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Sustaining Pecan Productivity Into the 21st Century

Second National Pecan Workshop Proceedings

Wagoner, Oklahoma
July 23–26, 1994

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FOREWORD

Pecan growers are facing rapid increases in production costs while the prices paid for their product has remained relatively constant. In recent years, a series of weather events reduced pecan production to record levels leading to a short term boost in prices paid to growers. These higher prices increased grower optimism for increased profitability in the 1993 cropping season and provided an opportunity to recover from losses sustained during previous seasons. Instead, a record high crop and the financial failure of a major sheller led to a price collapse. During the 1993 harvest season prices hardly covered harvest costs. In 1993, growers began the year expecting to recover from years of low production only to lose money or leave millions of pounds of native pecans in the field.

Also in 1993, the pecan industry became deeply divided over a single issue — the National Pecan Marketing Order. To some, the marketing order represented a positive effort to promote pecan sales, while others viewed the collection of assessments as needless government intervention in private business. Ultimately, the marketing order was defeated in 1993, sending repercussions well beyond the pecan industry. On April 1, 1994, the front page of the *Wall Street Journal* reported that the pecan industry was hopelessly divided and destined to lose market share.

Grower fears of government intervention during the Marketing Order debate have been misdirected. Instead of fearing the record keeping requirements imposed by the marketing order, growers, especially native pecan producers, should be greatly concerned with federal encroachments on private property rights. Most native pecan groves are located on alluvial soils associated with rivers and streams. The wetlands preservation provisions in the 1990 Clean Water Act have turned many of these productive groves into wetlands solely on the basis of an ill conceived definition for "wetlands". To adhere to the letter of the law, these native pecan producers will have to apply to the U.S. Army Corps of Engineers for a Section 404 exemption from the Clean Water Act before removing a single tree from the grove. Additional applications are necessary before a grower can make improvements to surface water drainage systems. The problems associated with the Clean Water Act are exacerbated by recent changes in the water management policy for federally controlled lakes and rivers. Increases in normal lake level elevations, made in the early 1980's in response to the 1980 drought, have increased the duration and frequency of up-stream flooding and have led to a significant rise in up-stream water tables. Throughout much of the native range in pecan, excessive flooding and high water tables are threatening to drown productive orchards.

Is the pecan industry destined to face a slow and painful decline? The dedicated pecan research and extension workers that made this conference possible continue to provide the knowledge base necessary to sustain the profitability of pecan culture. However, future efforts in these directions are becoming seriously limited by cuts in staffing and funding for pecan research and extension. Only a unified effort by both growers and shellers can turn the pecan industry around. First, the industry must work together to stabilize the pecan marketplace to a point where both growers and shellers can profit. Secondly, the industry must develop a strong, unified voice that is recognized by our nation's political leaders. Only through the political process can our industry work on issues that will impact the future of pecan culture and management. These issues include: strengthening support for pecan research and extension, expanding markets for new and value-added pecan products, and protecting personal property rights. Early evidence suggests that the hardships experienced by pecan producers in the early 1990's have served to strengthen the resolve of industry leaders to work towards rebuilding the pecan industry.

This workshop's objectives were the same as those of the first workshop: a) clarify the primary factors contributing to the cost-price squeeze, b) educate scientists as to the nature of the problem and how it interacts with other problems and disciplines, c) encourage cooperative efforts to address these problems, d) gain insight into new areas of research, and e) encourage greater communication among researchers.

We thank all those attending for their contributions, the program committee (James Dutcher, Esteban Herrera, Bruce Wood, Sharon von Broembsen, Scott Landgraf, José Peña, John McVay, William Reid, and Michael W. Smith) for their efforts in assembling a comprehensive program. Sincere thanks is extended to all those who participated on the program and to those who prepared their presentations for publication in this proceeding. Sincere thanks is also extended to Teri Sheriff for preparing this proceedings for publication and to the USDA-ARS for publishing and distributing the proceedings.

MEETING GROWER NEEDS

S. Landgraf[1]

INTRODUCTION

We are a part of a changing world that is an evolutionary process that is not complete. There is a certain amount of uncertainty that naturally occurs with pecans and pecan producers due to perennial nature and the longevity of the crop. It is difficult to change so easily varieties or spacing as is with shorter life crops. Pecan people have to be visionary patient stewards of the changing ecosystem.

There is a continual drive to find that perfect variety or that management technique that solves all production problems which probably does not exist. It seems that with pecans there needs to be a sense of moving more cautiously, scrutinizing the research efforts to assure no mistakes in pecan management. So many management techniques require multiple years to obtain factual, absolute results that have far reaching effects on the industries future. One wrong decision and the grower will be living with the mistake the rest of their life.

Today, the pecan industry must first survive, before there can be significant money for research. We must look at sustainable more effective long term management rather than for the one perfect variety or management technique. We have to be more specific to each management unit and develop the dependable practices to ensure consistent production of market development. The large swings in production must be reduced. The old adage "Bigger is Better" may not be true if bigger is not dependable and consistent.

CONSISTENT PRODUCTION

There are several factors that complement each other to develop a greater likelihood of consistent production. These factors are:

Hardiness is the ability of the tree to survive even under the most adverse conditions. When a disaster occurs, and it is unbelievable how well the tree survives and maintains a crop indicates its hardiness. Some refer to those trees that survive without special care as tough or healthy. The varieties that have stood the test of time are 'Western Schley' in the West and 'Stuart' in the East.

Elevation as related to air drainage and frost susceptibility has proven to be of greater significance than ever before, especially within the past five years. Bottom land areas where soils are deep are most susceptible to frost injury. Frost is a greater threat for young trees than older ones due to the vegetative growth that exists late in the season. For older trees, frost danger increases for later maturing varieties, although rainfall, nut load, hours of sunlight, heat units, and foliage pests can cause the nut maturity date to be delayed. Whether it is genetic, cultural, or environmental, delayed nut maturity increases the tree's vulnerability to frost. Higher elevations can provide a greater number of days for ripening before frost.

Drainage is an absolute requirement for even the most hardy tree to be productive. Water filling the soil pores that drive out the oxygen necessary for respiration of the tree roots will greatly limit productivity. High water tables are hidden factors that will cause hardiness to fade to severe deterioration and possible senescence. Surface drainage ditches must be maintained or created to allow water movement from the orchard site.

Spacing is considered a great limitation to production due to the competition that exists between trees for sunlight and moisture. Adequate spacing is required for consistent economical production, while tree removal is a difficult decision for most growers. It requires so much time to grow a tree and there is so many threats to tree health, removing one is quite a mental challenge. Where needed, there is probably no other cultural practice that will improve the consistency of production quicker than adequate spacing.

Genetics is the area that has the greatest opportunity for improvement. Oscar Gray was an enthusiast for finding the perfect variety of pecan. In his last days, he needed one more year to determine the best variety. Today some 20 years later, I have not come any closer to choosing that perfect variety for southern Oklahoma. My neighbors are saying "I do not like any of those papershells, I like those natives". The variety dilemma is pitiful. Never before in history are we facing the extreme threats of environmental safety and loss of chemicals that we so desperately need to grow the varieties that we have today. To survive, we must develop resistant or tolerant varieties to the pests that exist and will evolve in the future.

Fertilization in the proper ratios with the correct methods will greatly influence the hardiness and productivity of pecan trees. There are so many factors that affect the availability and uptake of nutrients that need understanding to better facilitate efficient utilization of the nutrients applied. Timing and application methods greatly influence tree vigor, nut quality, yield and return bloom. I feel that fertilization has an opportunity for quick impact on the

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[1] Pecan grower, Madil, OK

pecan industry. There is a lack of nutrient management that needs understanding and changed appropriately, to maximize yields.

Management strategies and philosophy are a prerequisite to successful pecan production. The days of harvesting what the good Lord provides for us is over. There will always be those years where there are wild pecans produced, but the lack of consistency of that production is impossible for any type of industry to build around. No doubt, management has to limit risk and become more effective while producers cannot reduce inputs to the point of limiting the dependability of production. Even yield has to be compromised in support of consistent production. Yield is one area where "Bigger is not necessarily better".

UNIFORMITY OF NUT QUALITY

How many times have you heard the comment "Too many sorry nuts"? No doubt the users of pecan could be more creative in marketing with a more uniform product. The pecan industry should understand the grower would like to produce every nut "plump to the end". There are numerous that impact nut quality, possibly some we have not even identified yet. Some of the most obvious factors are: Tree vigor, fruit set, variety, and post harvest handling.

Tree vigor is very difficult to differentiate from hardiness. It is the easiest understood when you visualize vigor as the fluff on top of hardiness. Hardiness is that staying ability, that may or may not produce nuts. Vigor is that excess energy over survival that initiates reproduction in potential nut production. The factors discussed above for consistent production are prerequisite to optimum tree vigor. If the tree is healthy and not limited by its environment, it is likely to produce higher yields of consistent quality nuts.

Fruit set definitely influences nut quality. Great opportunities exist with nut thinning shown by Dr. Mike Smith's work. This may be the most significant breakthrough in not only nut quality, but an equal influence on consistent production. I have used the mechanical thinning on some of my trees for the last four years and have been very impressed with the outcome. Thinning has truly saved trees destined for disaster and has turned them into a profitable producer.

Variety selection is complicated and presents an unclear picture of the pecan industry. Pecans are a perennial crop with a long life expectancy; and time exposes the tree to such a wide array of conditions. It takes many years to adequately evaluate a pecan variety. Even though there is such a time factor involved in variety development and selection, it is the area where some of the greatest positive impact on the pecan industry can occur. Long term observation of blocks of existing varieties could prove of significant importance in variety selection. An area that has not been given adequate consideration in variety selection is the interactions with soil type. These long term plots would need to be compared on several different soil types and sites.

Post harvest handling is an area that should not be so difficult to manage, since the pecans are in a sack and should be in the dry. Too often, the pecans lay in the barn long enough that quality begins to decline. There should be a financial reward for keeping the product fresh as possible. The next step is marketing, where exposure time can stretch out. There should be some incentives for maximizing freshness leading to reducing the time from field to the freezer. Growers should have more control over this area where they can have potentially greater impact on quality than most other areas.

COMPARATIVE COSTS OF PRODUCTION

The agricultural economists have a catchy phrase "comparative advantage" that describes several questions that our industry needs to answer. The answer to the questions should influence the direction of pecan research activities.

Can we afford to fight diseases with pesticides? Research is presently underway toward breeding disease resistance. Breeding is the only sustainable answer to the disease threat. For old varieties with disease problems, they may have to be removed. The work Dr. Von Bronsen has started truly approaches disease control from an Integrated Pest Management point of view. The availability of mezzo net for weather information is truly one step closer to assigning specific times for fungicide application. Due to the cost of fungicides and their application, an economic analysis should perfect every application. There is some economic threshold at which pecans grown with fungicides cannot be produced at a profit. Removal of whole orchards of certain varieties in the Southeast supports this point.

What are economic levels to control specific insects? To be competitive with production cost, absolute threshold levels must be established for each insect pest. Research by Dr. Smith and Dr. Eikenbary have shown some biological approaches to prevent significant insect infestations. The grower needs simple, straight forward scouting techniques that gives ready answers. The pheromone trap is a significant step toward those type threshold levels and monitoring.

How can an orchard floor be managed at least cost with minimum competition to pecan production? Clean till is undoubtedly one extreme toward minimizing weed and grass competition. Chemical treatments are quite effective, although the cost is not that different from clean till. Combinations of mowing and chemical applications should provide a preferred approach to floor management.

What about grazing livestock under pecan trees? Label requirements greatly limit pesticide applications and timing. With some of the new biological controls strategies, livestock could possibly have a greater opportunity in orchards. Grazing significantly reduces mowing and chemical costs, while providing added value to the system. Livestock recycle the nutrients contained in what they consume while haying removes the nutrients. Biological management systems should be studied to find the facts about livestock as a part of the system.

Are there compromises? In biological systems, compromises are requirements of the system. Actually, the cause and effect of each management practice is a series of compromising decisions. Top yields may not be actually the most profitable when the costs of a bumper crop is calculated. When there is reduced vigor, no crop the next year, dead limbs, or even dead trees as a result of that huge crop, something less looks better. Again, "Bigger is not always Best".

ENVIRONMENTAL SAFETY

Protection of the environment is a top shelf concern by the American public, causing some significant misunderstandings about agricultural production. Instead of land owners being a threat of the environment they manage, as a whole they are very concerned about its conservation. The difference comes from survival and economics in agriculture while environmentalists are to protect certain items at any cost.

Most producers are environmentalists! They are not necessarily trained professionals, they have learned to coexist with the ecosystem of which they manage.

The extremes on each side of the issue is probably wrong, and some compromise is what is most logical. I'm not aware of one grower that likes applying pesticides because of cost, and personal safety. The issue is good from the point of view that each extreme position has to comprise where we can coexist in a clean, safe environment.

HARVEST EASE AND SPEED

Pecans are considered as a labor intensive crop. Continued new innovations in harvest equipment has reduced the labor requirement and increased the percent of product harvested. There are some very important thresholds between equipment cost and volume to be harvested. Where is the economic threshold between wildlife depredation, increased yield with early harvest, and improved quality when compared to equipment investment?

Those early harvested nuts are more valuable, better quality, and usually provide larger yields. High moisture is usually an important factor with early harvest. Growers need guidelines on proper drying techniques with economic considerations. Now most growers let pecans dry on the tree in Oklahoma. Growers need information on equipment to handle and properly dry large volummes of wet nuts.

MARKETING PECANS

As mentioned above, the higher priced nuts are ready for market early with good quality. The better prices are associated with niche markets. For those who develop those markets, there is a significant advantage. It usually takes years of dedication and vision to develop a significant niche market.

Today on a larger scale, "Value Added" is something that provides great opportunity. When a raw product is enhanced in value by packaging, or adding a less expensive ingredient and processed to charge a higher price, the industry demands a greater share of the available market. As an industry, we need to encourage and support those efforts.

Several organized thrusts in accumulating pecans and selling at a more equitable price have been tried with some more successful that others. It seems that pecan producers are very difficult to organize due to their independence. The lack of confidence in marketing of pecans is a limitation to pecans becoming a more significant agricultural crop. I have been involved in several different efforts to be disappointed in their success. I question if the pecan industry can ever be organized.

SHELF LIFE

Through marketing efforts, shelf life is related to quality deterioration and there is a severe limitation. The red nut meat on the grocery store shelf has long been a concern. Some oil extraction research is presently underway and is providing a great opportunity for extending shelf life. Some oil extraction research presently underway provides great opportunity for extending shelf life and marketing opportunities. Due to the lack of refrigeration for overseas shipment or its prohibitive cost, international marketing is also limited. Extended shelf life will greatly enhance international as domestic marketing opportunities.

SUMMARY

Growers need research projects to address some of the more obvious problems we confront in staying competitive with other nut crops. Consistent production is the greatest threat to keeping our limited markets for pecans, where the hardiness combined with good management practices will need to be redefined to facilitate a pecan crop every year. Consistent production provides good supply that leads to opportunities for market development.

Markets can further be stimulated with uniformity in nut quality. All factors that influence the pecan tree's vigor should be further investigated for their impact on quality, while those management practices should be economically scrutinized for their benefit to the industry. Compromises in management have to be reviewed to find the best decision in every situation. The goal for every research project should be to maintain consistent sustainable pecan production.

AN UPDATE ON HICKORY SHUCKWORM RESEARCH

J.K. Collins[1], G.H. Hedger[2] and R.D. Eikenbary[1]

INTRODUCTION

The hickory shuckworm, *Cydia caryana* (Fitch) (Lepidoptera: Tortricidae), has been considered one of the most important pecan pests attacking pecan by growers and entomologists in the southeastern United States. This notoriety for the hickory shuckworm originated, most likely, because of the: (1) emergence of adults over an extended period from approximately April 1 through October (Calcote & Hyder 1979 & 1980); (2) the long period of time that may need insecticide applications; (3) the difficulty of sampling and identifying this insect; and (4) the lack of validated action thresholds. The timing of an insecticide was aided greatly by the introduction of the blacklight traps for hickory shuckworm surveys and control (Tedders & Edwards 1972, 1974; Tedders et al. 1972; Strother & McVay 1978; and McVay & Ellis 1979). However, the technique of using the blacklight traps was only accepted for monitoring pest populations by a few growers which were in Alabama (McVay, Personal Communication) and research entomologists.

The recent development of the hickory shuckworm pheromone (Smith et al. 1987, McDonough 1990) provided a practical method of identifying and monitoring this pest, but action thresholds for applying insecticide applications are still lacking. The use of the hickory shuckworm pheromone has been aided greatly by the research of McVay et al. (1991). This research included trap type, effectiveness, vertical distribution (trap height), horizontal distribution (trap placement within the canopy), and cardinal direction. There have been some reports from growers and entomologists that the pheromone does not attract the male hickory shuckworm moths during the summer (June and July), but does work early in the season (April and May) and after the half-shell hardening, which occurs approximately August 15.

Additionally, some scientists have stated that there has been tremendous variation in pheromone trap catches possibly due to the lack of attraction of the shuckworm pheromone lures from different companies. Therefore, the objectives of this research study were to: (1) determine the attraction of the hickory shuckworm lures over the season with materials provided by Trece, Scentry, and the Yakima, WA, USDA-ARS laboratory, and (2) compare the hickory shuckworm pheromone trap catch trend in the same locality where we collected hickory shuckworm moths in blacklight traps in a previous 5 year study (Hall & Eikenbary, Unpublished).

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[2] Noble Foundation Horticulturist, Ardmore, OK

MATERIALS AND METHODS

For the experiment, the same pheromone components, E8, E10-12 acetate, were used in an abandoned pecan orchard. The pheromones were placed in Scentry wing pheromone traps and placed in a pecan orchard on the campus of Oklahoma State University. This particular orchard was ideal for testing the pheromone in that the orchard is abandoned so there has been no chemical applications or IPM practices occurring for several years. The area has native and improved pecan trees with phylloxera galls (*Phylloxera* spp.) which provide an early season habitat for hickory shuckworm development (Dinkins & Reid 1988, Eikenbary et al. 1990).

The traps were placed in the tree using a 2.5 cm X 6.09 piece of electrical conduit. A hook was fashioned from 3/8" rebar with a hole drilled in the end opposite of the hook. A piece of #12 copper wire was inserted into the hole to served as the pulley. Baling twine was placed through the copper wire loop before the hook was placed in the tree. The trap was attached to the baling twine and pulled up into place (Robert Morrison, Personal Communication. Dept of Statistics, Okla. State Univ., Stillwater, OK).

The hickory shuckworm populations were monitored from 10 July 1993 to 31 October 1993, and 1 April 1994 to 3 October 1994. During this period, 20 traps were placed in the orchard, 5 traps with each of the three pheromones (Trece, Scentry and USDA prepared) and 5 traps which had no pheromone (blanks). The traps were placed at least 25 m apart in the outer portion of the canopy, and a trap count was made every three days. The blanks were counted the day after the pheromone count was made in order not to contaminate the blanks. The concentration and purity of each of the pheromones are in table 1.

RESULTS

The data were analyzed using SAS (SAS Institute 1985). The blanks were analyzed with the three pheromone types in the first ANOVA and GLM procedure. Using the analysis in this method, significant differences in the data were noted at ($P < 0.05$). This should be the case since hickory shuckworms were not caught in the traps containing the blanks. The data were analyzed again using ANOVA and GLM without the data from the blanks included in the analysis. The analysis concluded there were no significant differences in the three pheromones. The data were also subjected to linear and quadratic analysis to determine if any differences could be detected in the three pheromones tested. No significant differences were seen between the

three pheromones by the two methods of analysis. There were significant differences detected by date and by trees (F>0.0001).

It should be noted that there were no independent treatments since all the traps were in the same orchard. It has been reported that traps should be at least one half mile apart to adequately evaluated the pheromones (Reid 1993).

DISCUSSION

The research completed in the past two growing seasons indicated that all three pheromones evaluated were effective in attracting the male shuckworm to the pheromone lures in the traps.

The traps were observed and moths removed and recorded every three days for the periods 26 July to 31 October 1993 and 1 April thru 3 October 1994. During these periods, the populations of hickory shuckworm fluctuated greatly most likely due to weather conditions and natural population variations. The data obtained from these portions of the growing seasons indicate that the traps are effective in attracting male hickory shuckworms if they are present in the orchard. It is very difficult to know what is actually happening with populations in the tree since there is not an effective method of sampling the trees for the hickory shuckworm.

In this particular orchard, the traps were effective in attracting males to the traps during the period of June thru July 1994 (Figure 1). It has been reported by growers and entomologists that during this period of time the traps are not effective in attracting the males. Calcote and Hyder (1979) monitored emergence of hickory shuckworm from the shucks over a 3 yr. period and found during 1976 hickory shuckworm were emerging during June and July, but during 1977 and 1978 from June thru July there was no hickory shuckworm emergence from the shucks (Figure 2). When comparing the pheromone data to the blacklight data (Hall & Eikenbary, Unpublished) for June thru July, 1994, the trap catch for the pheromone is about half of the blacklight trap catch. Blacklights attract both male and female moths whereas the pheromone trap attracts only males. Thus, there is an unequal attraction of hickory shuckworms to pheromone traps versus blacklight traps. Our data suggests the traps are an effective method of monitoring the male hickory shuckworm during this period of time. The hickory shuckworm pheromone probably attracts the male moths in proportion to the total population in an area. Therefore, when few moths are caught by the pheromone traps or blacklight traps in the summer, it is a result of few moths present in that locality. This can be alleviated somewhat by placing the pheromone traps in pecan trees that have a history of hickory shuckworm populations.

Use of the pheromone traps for determining spraying times (action threshold) for control of hickory shuckworm populations may require additional field research, but the traps do give some indication that the insect is present in an orchard. By monitoring weather data and pheromone trap catches, blacklight traps, and emergence of the hickory shuckworm from the pecan shucks for the growing season, the data may help explain the fluctuations with shuckworm populations.

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Table 1. Concentration and purity of the pheromones lure provided by the individual labs.

Pheromone	Concentration (ug/speta)	Purity
USDA HSW pheromone	50ug	99.9%
Scentry	50ug	99.9%
Trece	50ug	99.9%

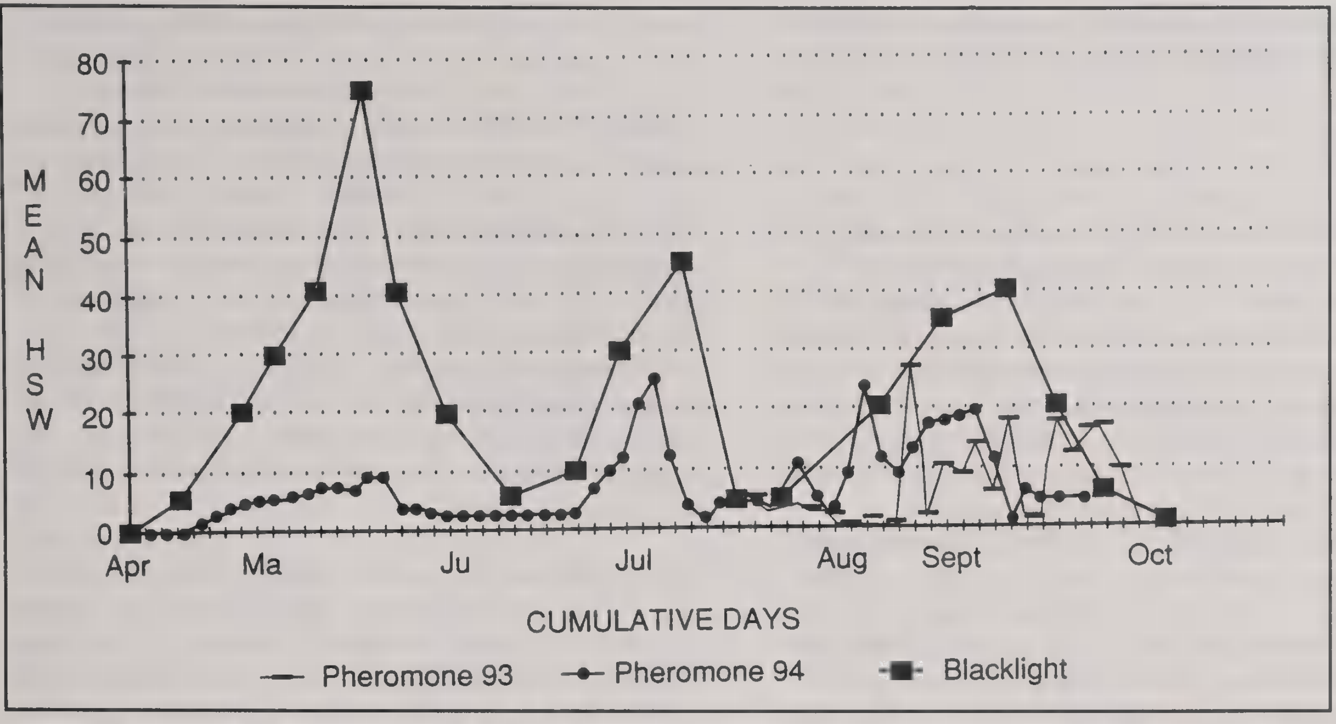

Figure 1. Mean hickory shuckworm trap catch over a 5 year period for the blacklight trap and over the 1993 and 1994 growing season for the hickory shuckworm pheromone trap.

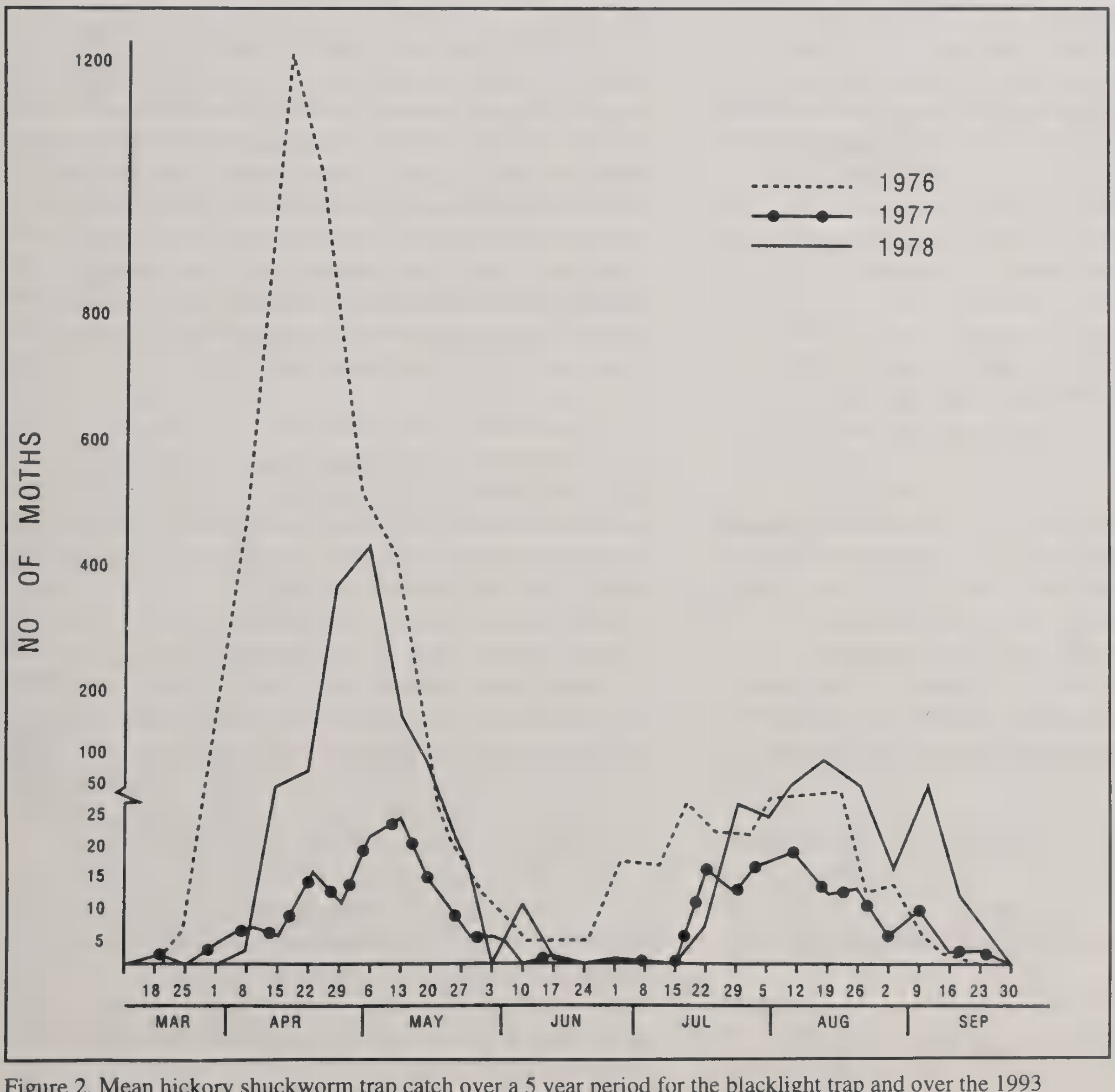

Figure 2. Mean hickory shuckworm trap catch over a 5 year period for the blacklight trap and over the 1993 and 1994 growing season for the hickory shuckworm pheromone trap.

INTERCROPPING PECAN ORCHARDS WITH LEGUMES: ENTOMOLOGICAL IMPLICATIONS

J.D. Dutcher[1]

Conservation of natural enemies is achieved in certain crops by reducing the risks to natural enemies of low plant diversity and insecticide toxicity in the crop. Predators of the pecan aphids are conserved by intercropping the orchard floor and selective insecticides. Recent research has indicated that: the aphidophaga are more abundant in the orchard floor when intercrops are present; ants tending pecan aphids reduce predator populations; ladybeetles can be attracted from the intercrop into the tree crown. However, the response of pecan aphid populations is quite variable to intercrops, predator attractants, and insecticide barriers to partition red imported fire ant foraging. Insecticides commonly used in pecan pest management are highly toxic to ladybeetles. Lacewings have some tolerance to the insecticides. The resurgence response of pecan aphid populations to carbaryl and other insecticides occurs whenever these materials are applied against nut pests. Biological control of pecan aphids was attempted by enhancing aphidophaga with a series of relay intercrops planted in the tree rows between the herbicide strips. Intercropped orchards had more aphidophaga on the orchard floor than mowed sod. Pecan aphid populations were reduced in some orchards, particularly, during the initial logarithmic increase phase of aphid population development. Consistent reductions in pecan aphisd will require more aggressive conservation methods.

When organophosphate and carbamate insecticides became ineffective for control of pecan aphids in the late 1970's. The pyrethroids, fenvalerate and cypermethrin were developed for broad spectrum insect control. The development of resistance in pecan aphids to pyrethroid insecticides (Dutcher and Htay 1985) and the sparse number of chemical alternatives led to an increased interest in host plant resistance and biological control and more effective placement of systemic insecticides (Dutcher and Harrison 1984). Host plant resistance is evident in a few cultivars (Kaakeh & Dutcher 1994) but is difficult to implement in established orchards of susceptible cultivars. For these locations research has focused on enhancement techniques for native aphidophaga (naturally occurring insect predators and parasites of the pecan aphids). Low plant diversity and insecticide toxicity are the main risk factors to predatory insects in many cropping systems and conservation of predators can be achieved by many techniques (Dutcher 1993) that reduce these risks. The problem with relying on native aphidophaga alone for control of pecan aphids is that they arrive after the pecan aphid populations have caused a considerable amount of damage. The pecan aphids have high rates of natural increase (Kaakeh and Dutcher 1992a) and aphid populations quickly outpace the predator populations before biological control is achieved. Intercrops can be used to raise alternative prey aphids and in turn raise aphidophaga. Legumes as intercrops have the added benefits of improving the soil and controlling weeds and these are balanced by the risks of bringing kernel-feeding Hemipterans and possibly root-feeding nematodes into the orchard. They also may compete with the pecan tree for nutrients in the soil. These risks are minimized when the intercrops are harvested before they set seed and planted in the middle of the sod strip in the tree row.

Pesticides applied to control nut-feeding insect pests are highly toxic to the aphidophaga (Hurej and Dutcher 1994a and 1994b, Mizell and Schiffhauer 1990) and aphid diseases (Pickering et al. 1990). Resurgence of aphids following the application of pesticides is quite common (Dutcher and Htay 1985). Pecan aphid control options include: preventive control with the systemic insecticide, aldicarb, applied to the soil; foliar sprays of insecticidal soap, methomyl, disyston or endosulfan or dimethoate when aphids increase to an injurious level; enhancement of natural biological controls. Preventive treatment with aldicarb offers good aphid control but rainfall may reduce the residual efficacy. Foliar sprays have mixed efficacy between orchards and between seasons. Native biological controls are not reliable or may not be present in sufficient populations to control pecan aphids. Abiotic factors, particularlytemperature extremes (Kaakeh and Dutcher 1992) and rainfall Kaakeh and Dutcher 1993) can regulate pecan aphid populations but are not reliable.

Conservation of natural enemies with intercropping shows some promise. The type of plants used as intercrops in pecan orchard effect the densities of alternate prey aphids and aphid predators on the orchard floor (Bugg and Dutcher 1989, 1993, Bugg et al. 1990). A full season intercropping strategy has been proposed (Bugg et al. 1991). Up until this time the intercropping had little or no effect on the density of pecan aphids in the tree. In fact, there was some indication that an alternate prey aphid population in the intercrop could attract predators out of the pecan tree if both pecan aphids and alternate prey aphids were present at the same time (Bugg and Dutcher 1989). Also, red imported fire ants, when tending an aphid infestation to obtain honeydew, are important regulators of aphid predators either in the intercrop (Bugg and Dutcher 1989) or in the tree (Tedders et al. 1990). A more aggressive orchard floor management scheme was tested during 1993 and 1994 in Sumter Co., Georgia and the first years results are reported here. In this study, tree trunks were treated with chlorpyrifos to prevent ant foraging in the tree and intercrops were cut when pecan aphids became abundant.

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METHODS AND MATERIALS

An experiment was set out to measure the impact of intercrops on the abundance of pecan aphids and beneficial insects in Sumter Co. The site had intercrops of the hairy indigo, *Indigofera hirsuta* and hemp sesbania, *Sesbania exaltata*, sown into the sod in mid-June (at a seed rate of 12 kg/ha of actual tilled area) as summer annuals in 2.6 m wide mowed strips between the tree rows with a no-till planter of pecan orchard to determine the ability of the intercrops to provide alternate prey items for general predators that feed on pecan aphids. The strips were mowed with a sickle bar mower in mid- September to prepare the orchard as a harvesting surface. The intercrops were planted among trees with and without chlorpyrifos barrier (Lorsban 4E (Dow Chemical Co.) at a concentration of 20 ml formulation per liter) sprayed on the trunk to prevent foraging of the red imported fire ant in the trees. Pecan aphids and associated beneficial insects were sampled on two consecutive days each week so that population size and relative growth could be estimated.

RESULTS AND DISCUSSION

At Sumter Co., in 1993, hemp sesbania sustained low populations of the greenhouse whitefly and cowpea aphid during the early fall and these were associated with a convergent lady beetles. We did not attract significant populations of the sevenspotted ladybeetle, *Olla v-nigrum*, or *Harmonia axyridis* (Coleoptera: Coccinellidae) to the intercrop. Hairy indigo grew very poorly at the Sumter Co. site. Red imported fire ant foraging was high in the trees and on the ground during the entire season. The intercrops were cut in the second week of September and the pecan aphids responded in several ways. The combined populations of yellow pecan aphid and blackmargined aphid (Figs. 1-11) peaked and declined from mid-September to mid-October (Day 257 - 286) in the intercrop and fire ant exclusion treatments. As aphid populations in the Schley trees first started to increase populations were higher were ants were foraging in the tree (Fig. 2) and there was no intercrop effect. On the same day in Stuart trees the aphids were lower in the trees with intercrops and ants did not have an effect. On the following day (258, Fig. 3) there was a significant effect of ant and intercrop treatments that was the most consistent of any of the sample dates. Here, the pecan aphids in both varieties were highest when both ants and intercrops were not present, otherwise, aphids were low. One week later on Day 264 (Fig. 4) there were no apparent differences between treatments with respect ot pecan aphid density. On day 265 (Fig. 5) trees without ants had fewer aphids. On the next to sample date (271, Fig. 6) aphids were significantly higher in the Stuart than in the Schley trees. On Day 272 (Fig. 7), a consistently large population of aphids occurred in the 'Stuart' trees with intercrops and without ants. During Days 278 and 279 (Fig. 8 & 9) only variety differences were significant. Then on Day 285 (Fig. 10) in Schley trees pecan aphids were higher with ants and without intercrops. In the Stuart trees pecan aphids were higher without ants and with intercrops than in any other treatments. Finally, on Day 286 (Fig. 11) there were no significant differences in aphid density, sexual forms were common on all trees and parthenogenetic populations were declining. These results can be interpreted in several ways but indicate that an even more aggressive set of treatments, such as a relay cropping scheme (Fig. 12) need to be applied to acheive consistent reductions in pecan aphids. In 1994, attractants were applied to the pecan trees to move ladybeetles into the trees while the intercrops were in the field. The effects of these treatments will be the subject of another article.

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Key to figures of 1993 Sumter Co. site variety, ant foraging and intercrop effects on pecan aphid density

The design measured main effects of 2 varieties,+/- ants, +/- intercrops and interactions between these binary treatments.

Pecan aphid density is recorded as aphids per compound leaf where the sum of the numbers of blackmargined aphid adults, yellow pecan aphid adults, and so-called 'yellow aphid nymphs' are referred to as aphids.

Beneficial insects were recorded as common when they were found in more than 2% of the samples, rare when that were found in 1% of the samples. LWE= lacewing eggs, LWP= lacewing pupae, LWL = lacewing larvae, PA = parasitized aphid mummies, SPID = spider, SYR= syrphid larvae, NB = nabid adults or nymphs, AB = assasin bug adults or nymphs, ABE = assasin bug eggs, LBE = ladybeetle eggs, LBL = ladybeetle larvae, LB = ladybeetle adults, LBP = ladybeetle pupa.

Figure 1

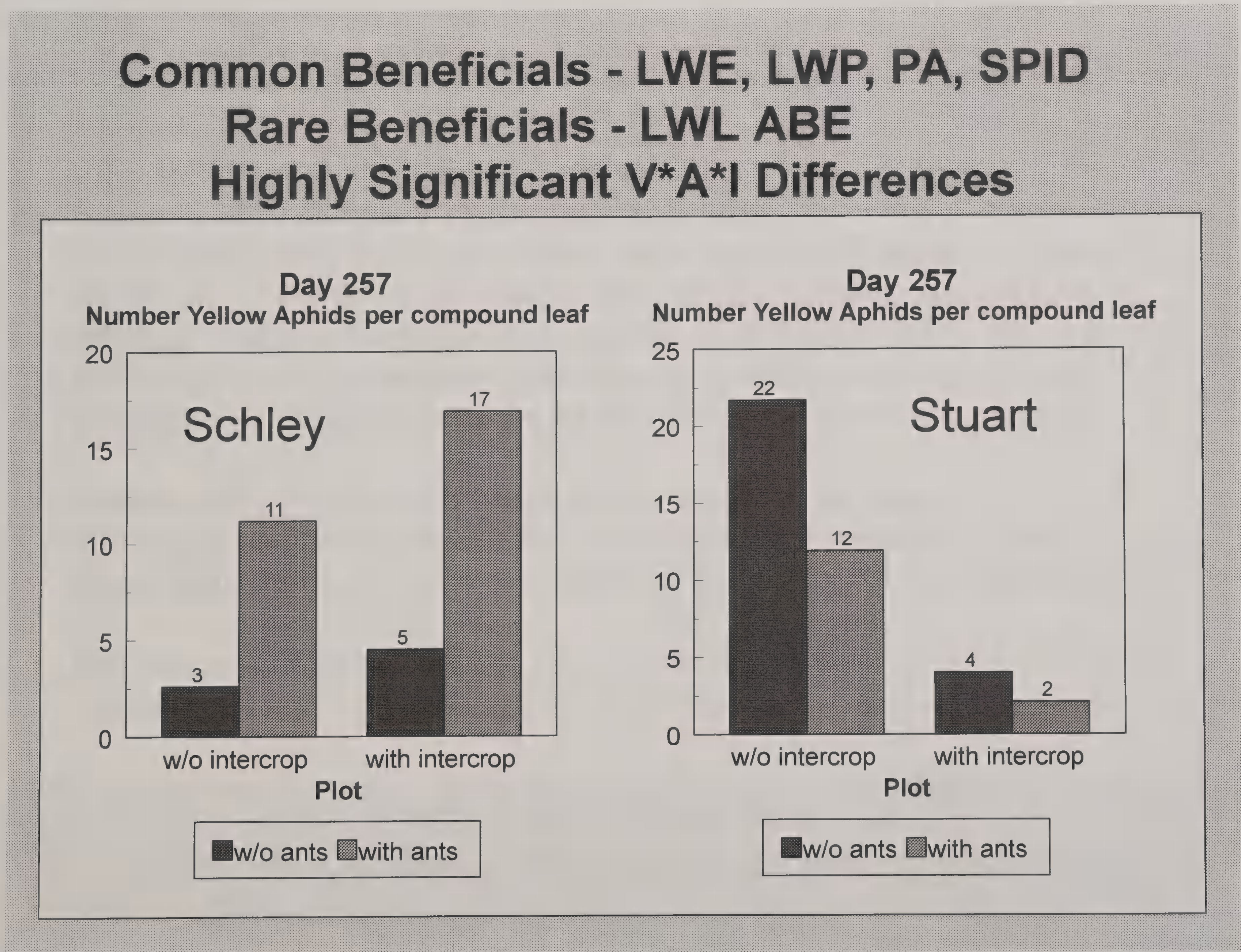
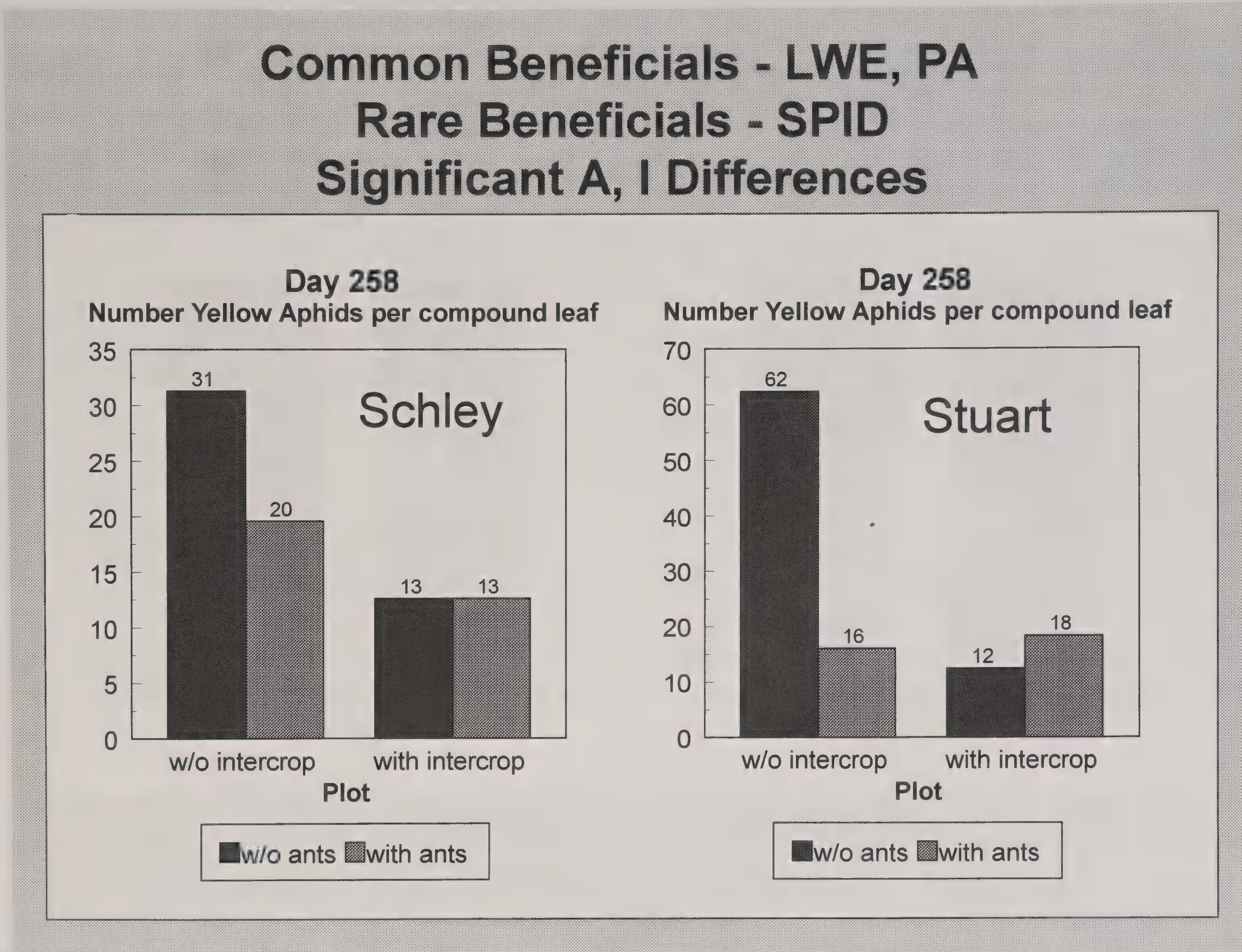

Common Beneficials - LWE, LWP, PA, SPID
Rare Beneficials - LWL ABE
Highly Significant V*A*I Differences
Day 257
Number Yellow Aphids per compound leaf
Schley
20
15
10
5
0
3
11
5
17
w/o intercrop
with intercrop
Plot
w/o ants
with ants
Day 257
Number Yellow Aphids per compound leaf
Stuart
25
20
15
10
5
0
22
12
4
2
w/o intercrop
with intercrop
Plot
w/o ants
with ants

Figure 2



Common Beneficials - LWE, PA
Rare Beneficials - SPID
Significant A, I Differences
Day 258
Number Yellow Aphids per compound leaf
Schley
35
30
25
20
15
10
5
0
31
20
13
13
w/o intercrop
with intercrop
Plot
w/o ants
with ants
Day 258
Number Yellow Aphids per compound leaf
Stuart
70
60
50
40
30
20
10
0
62
16
12
18
w/o intercrop
with intercrop
Plot
w/o ants
with ants

Figure 3

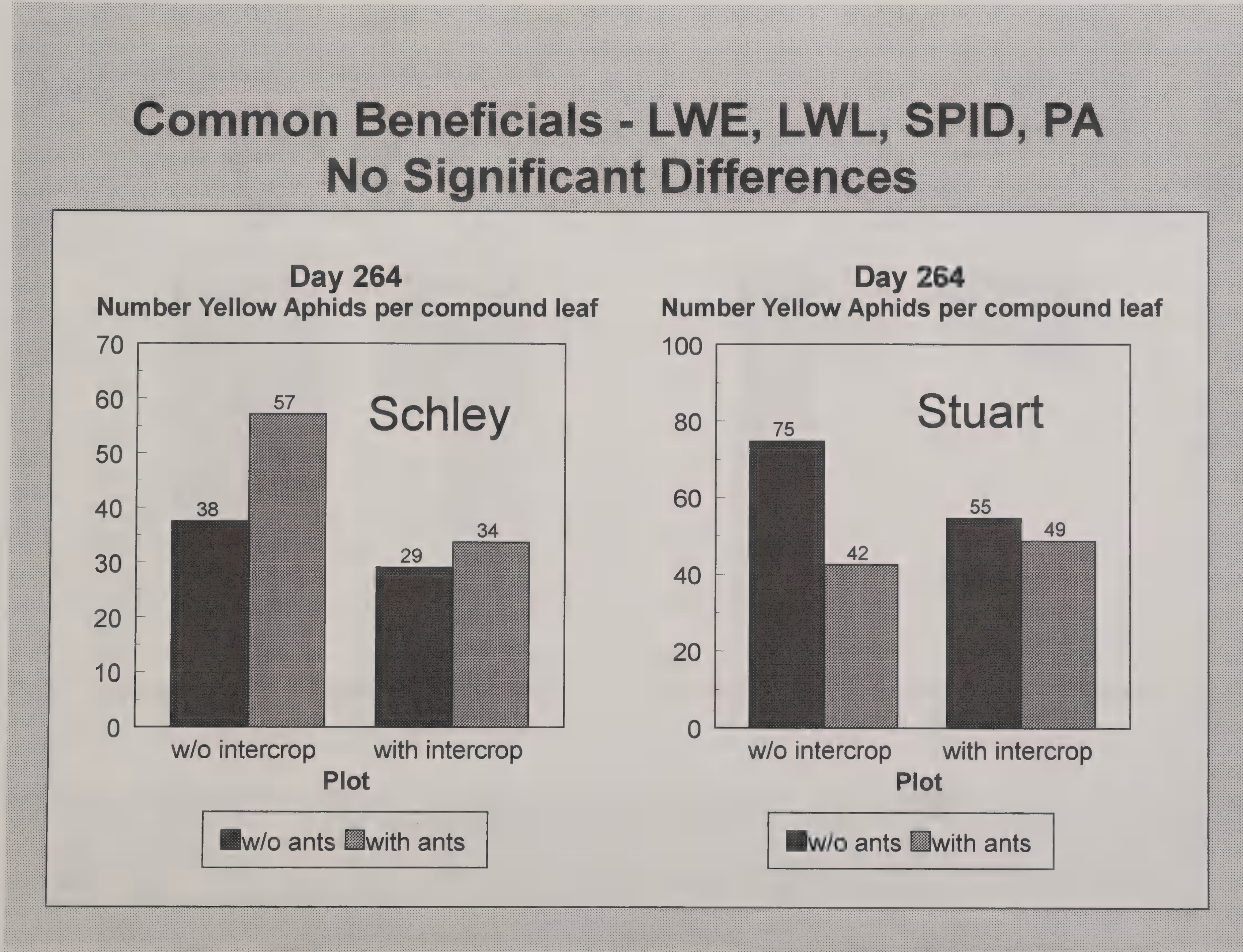

Common Beneficials - LWE, LWL, SPID, PA
No Significant Differences
Day 264
Number Yellow Aphids per compound leaf
70
60
50
40
30
20
10
0
38
57
29
34
Schley
w/o intercrop
with intercrop
Plot
w/o ants
with ants
Day 264
Number Yellow Aphids per compound leaf
100
80
60
40
20
0
75
42
55
49
Stuart
w/o intercrop
with intercrop
Plot
w/o ants
with ants

Figure 4

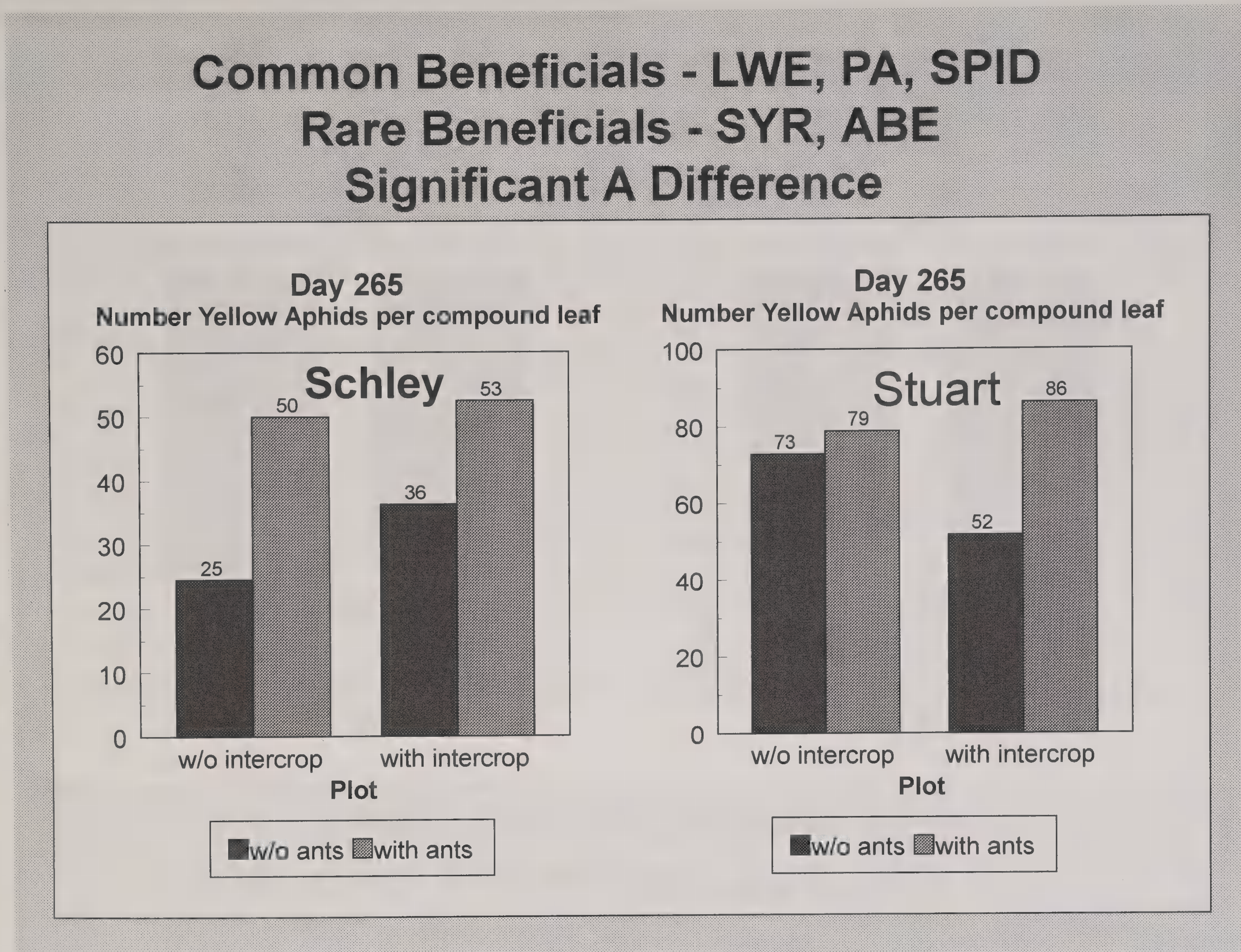

Common Beneficials - LWE, PA, SPID
Rare Beneficials - SYR, ABE
Significant A Difference
Day 265
Number Yellow Aphids per compound leaf
Schley
60
50
40
30
20
10
0
25
50
36
53
w/o intercrop
with intercrop
Plot
w/o ants
with ants
Day 265
Number Yellow Aphids per compound leaf
Stuart
100
80
60
40
20
0
73
79
52
86
w/o intercrop
with intercrop
Plot
w/o ants
with ants

Figure 5

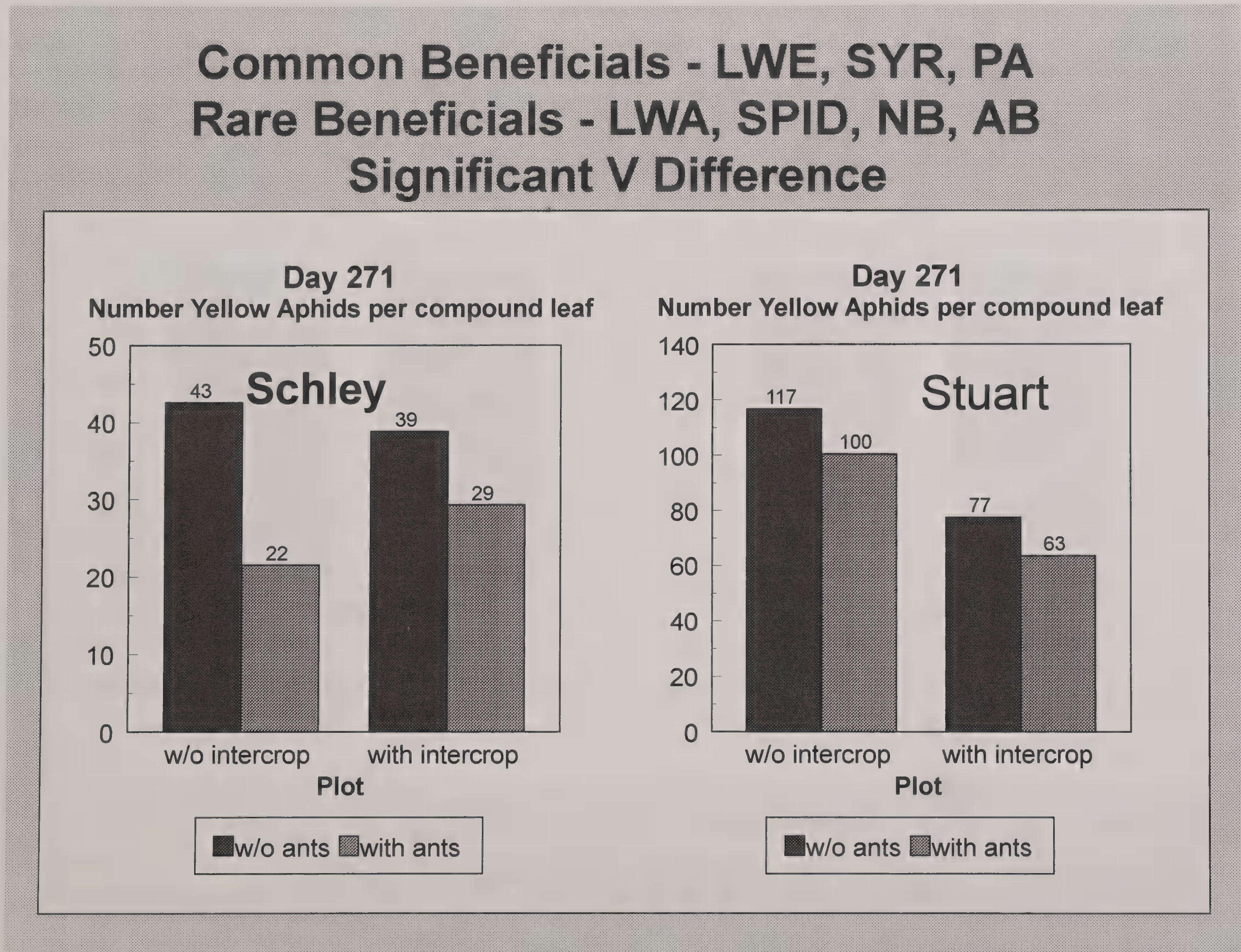

Common Beneficials - LWE, SYR, PA
Rare Beneficials - LWA, SPID, NB, AB
Significant V Difference
Day 271
Number Yellow Aphids per compound leaf
Schley
50
40
30
20
10
0
43
22
39
29
w/o intercrop
with intercrop
Plot
w/o ants
with ants
Day 271
Number Yellow Aphids per compound leaf
Stuart
140
120
100
80
60
40
20
0
117
100
77
63
w/o intercrop
with intercrop
Plot
w/o ants
with ants

Figure 6

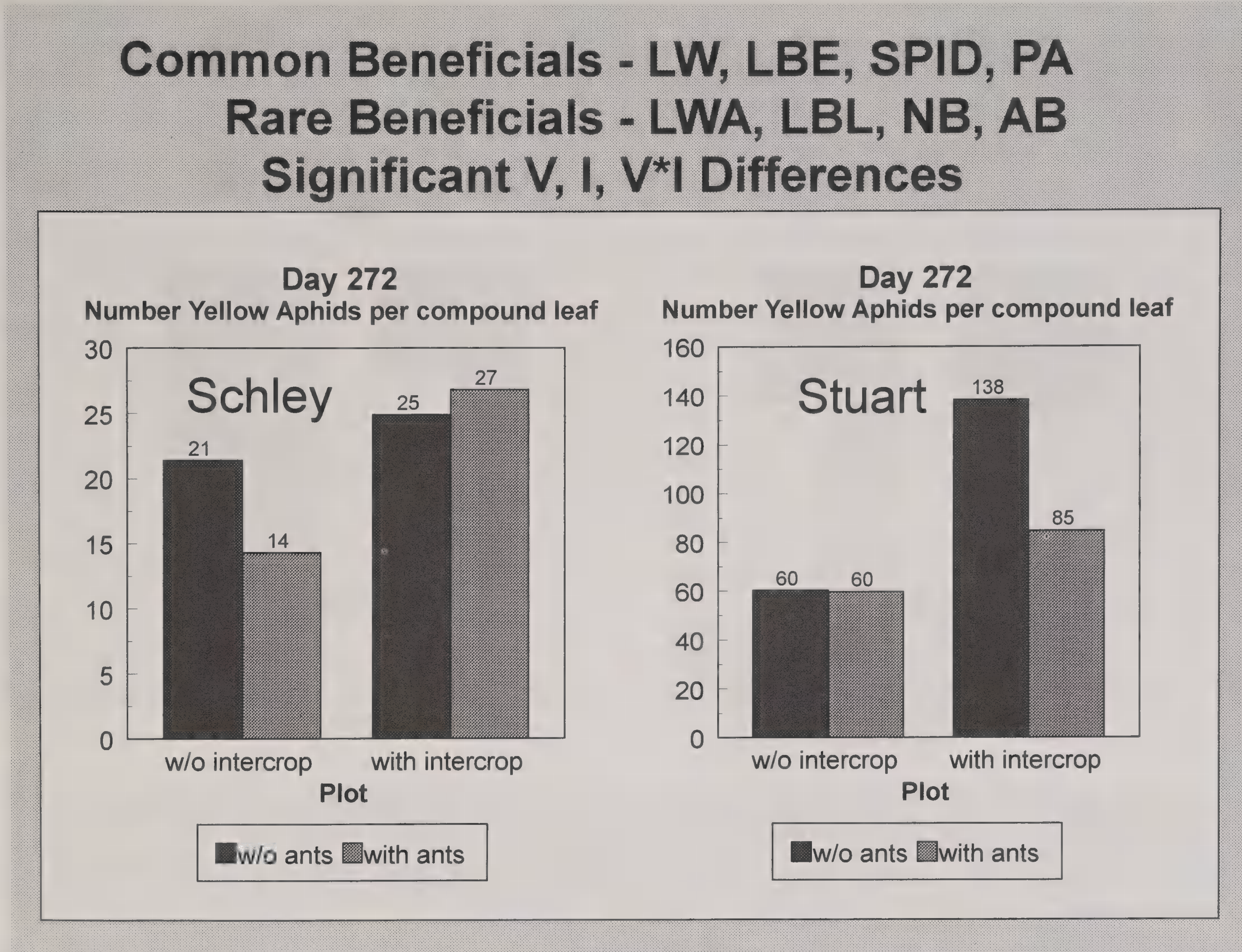
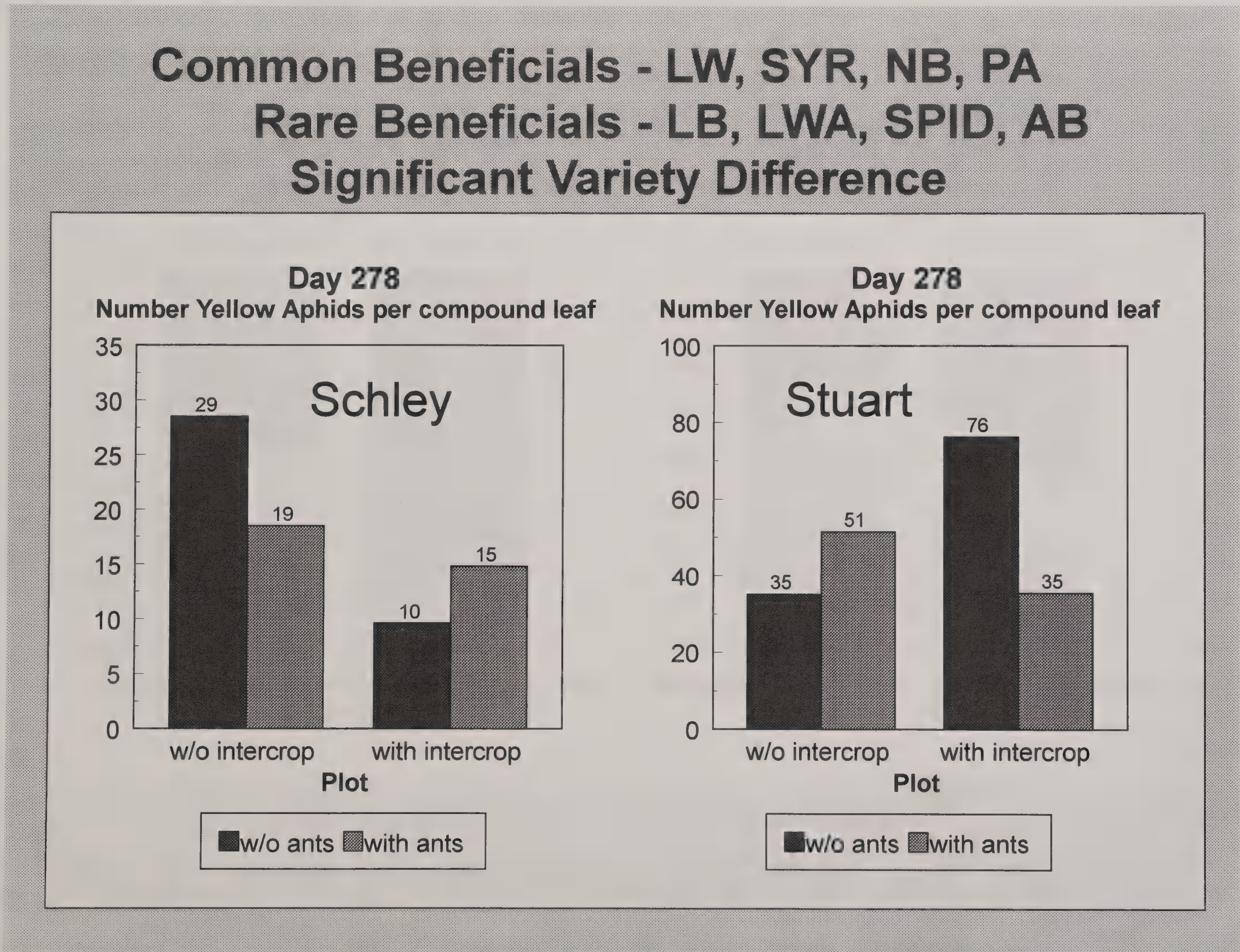

Common Beneficials - LW, LBE, SPID, PA
Rare Beneficials - LWA, LBL, NB, AB
Significant V, I, V*I Differences
Day 272
Number Yellow Aphids per compound leaf
Schley
30
25
20
15
10
5
0
21
14
25
27
w/o intercrop
with intercrop
Plot
w/o ants
with ants
Day 272
Number Yellow Aphids per compound leaf
Stuart
160
140
120
100
80
60
40
20
0
60
60
138
85
w/o intercrop
with intercrop
Plot
w/o ants
with ants

Figure 7



Common Beneficials - LW, SYR, NB, PA
Rare Beneficials - LB, LWA, SPID, AB
Significant Variety Difference
Day 278
Number Yellow Aphids per compound leaf
Schley
35
30
25
20
15
10
5
0
29
19
10
15
w/o intercrop
with intercrop
Plot
w/o ants
with ants
Day 278
Number Yellow Aphids per compound leaf
Stuart
100
80
60
40
20
0
35
51
76
35
w/o intercrop
with intercrop
Plot
w/o ants
with ants

Figure 8

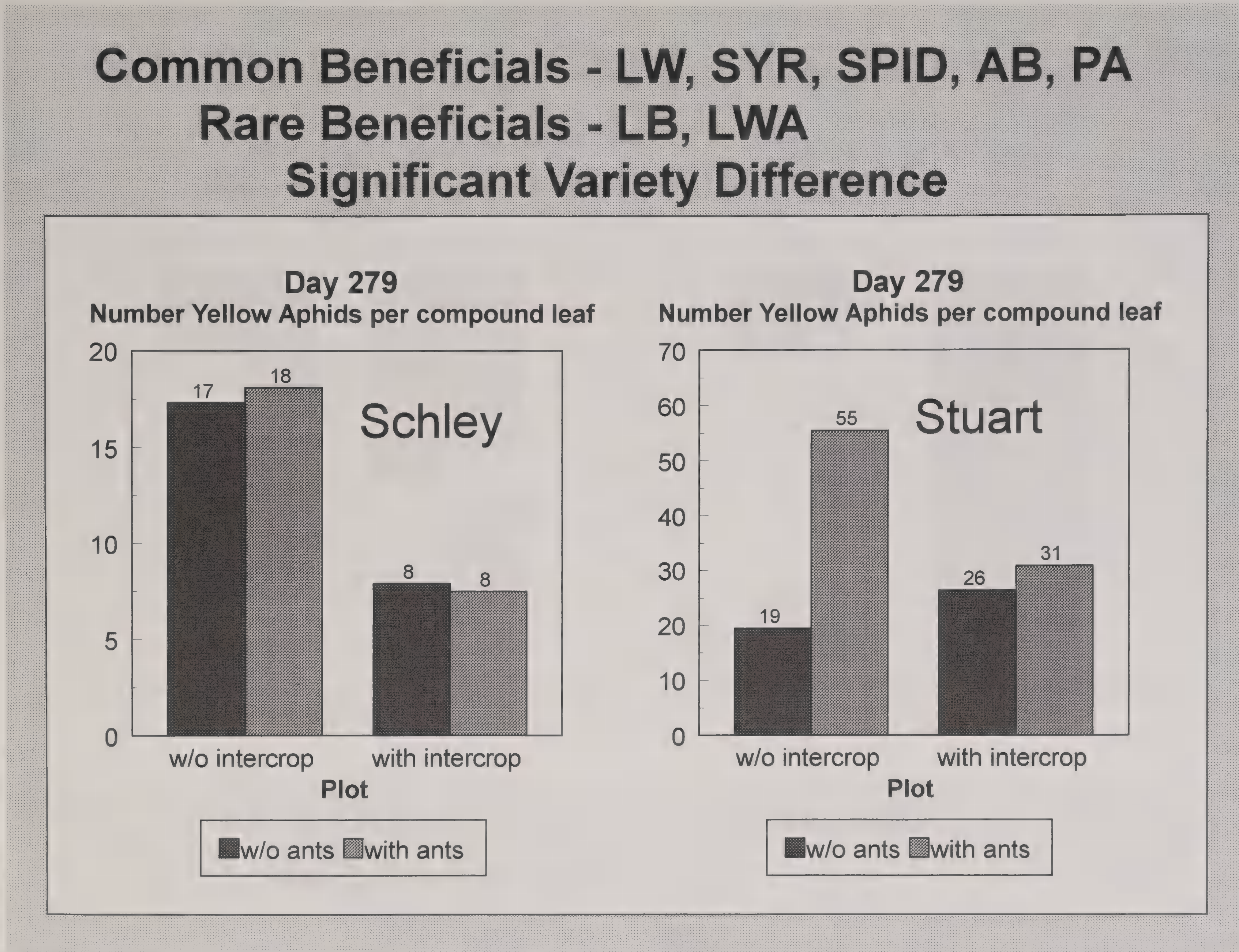

Common Beneficials - LW, SYR, SPID, AB, PA
Rare Beneficials - LB, LWA
Significant Variety Difference
Day 279
Number Yellow Aphids per compound leaf
Schley
20
15
10
5
0
17
18
8
8
w/o intercrop
with intercrop
Plot
w/o ants
with ants
Day 279
Number Yellow Aphids per compound leaf
Stuart
70
60
50
40
30
20
10
0
19
55
26
31
w/o intercrop
with intercrop
Plot
w/o ants
with ants

Figure 9

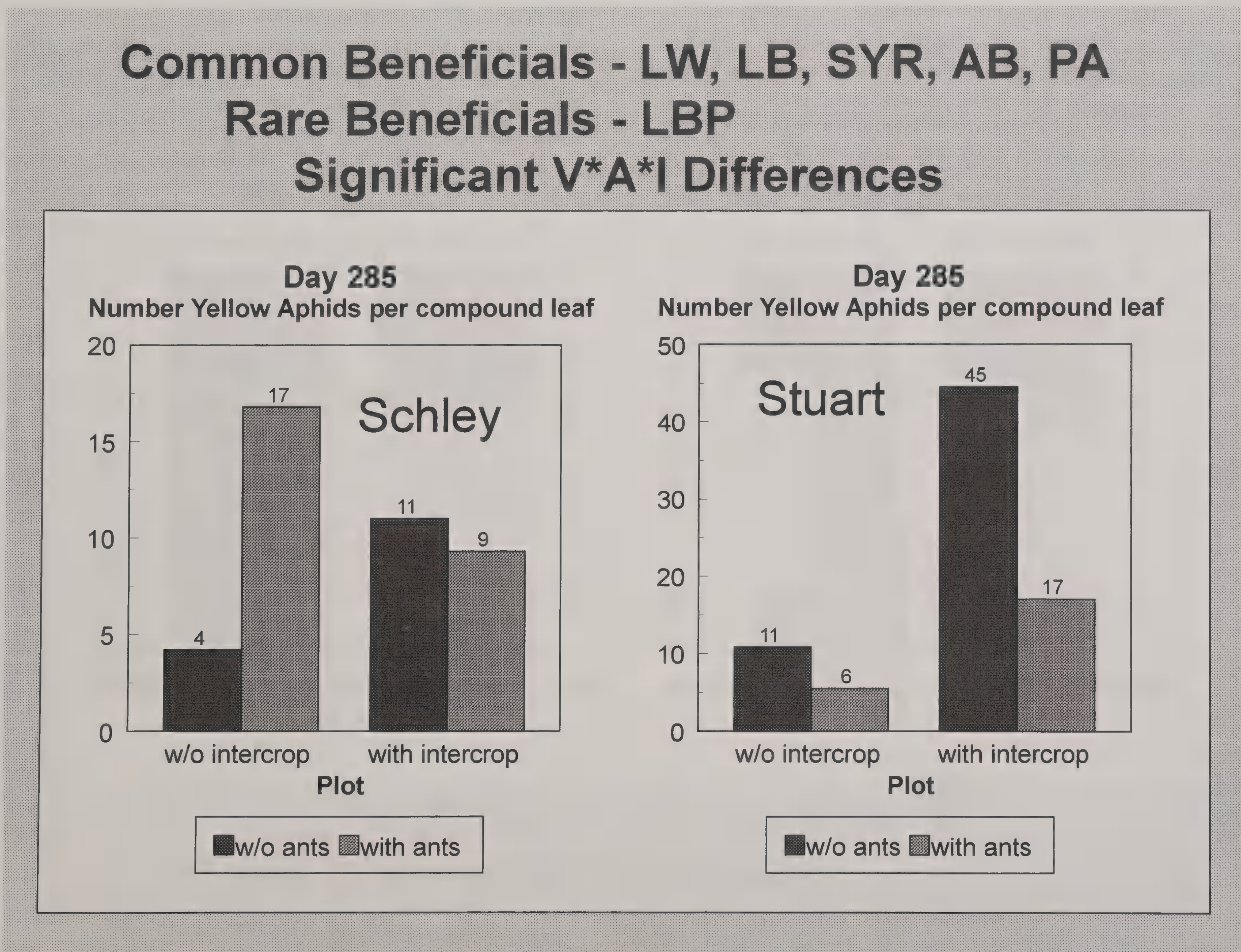

Common Beneficials - LW, LB, SYR, AB, PA
Rare Beneficials - LBP
Significant V*A*I Differences
Day 285
Number Yellow Aphids per compound leaf
Schley
20
15
10
5
0
4
17
11
9
w/o intercrop
with intercrop
Plot
w/o ants
with ants
Day 285
Number Yellow Aphids per compound leaf
Stuart
50
40
30
20
10
0
11
6
45
17
w/o intercrop
with intercrop
Plot
w/o ants
with ants

Figure 10

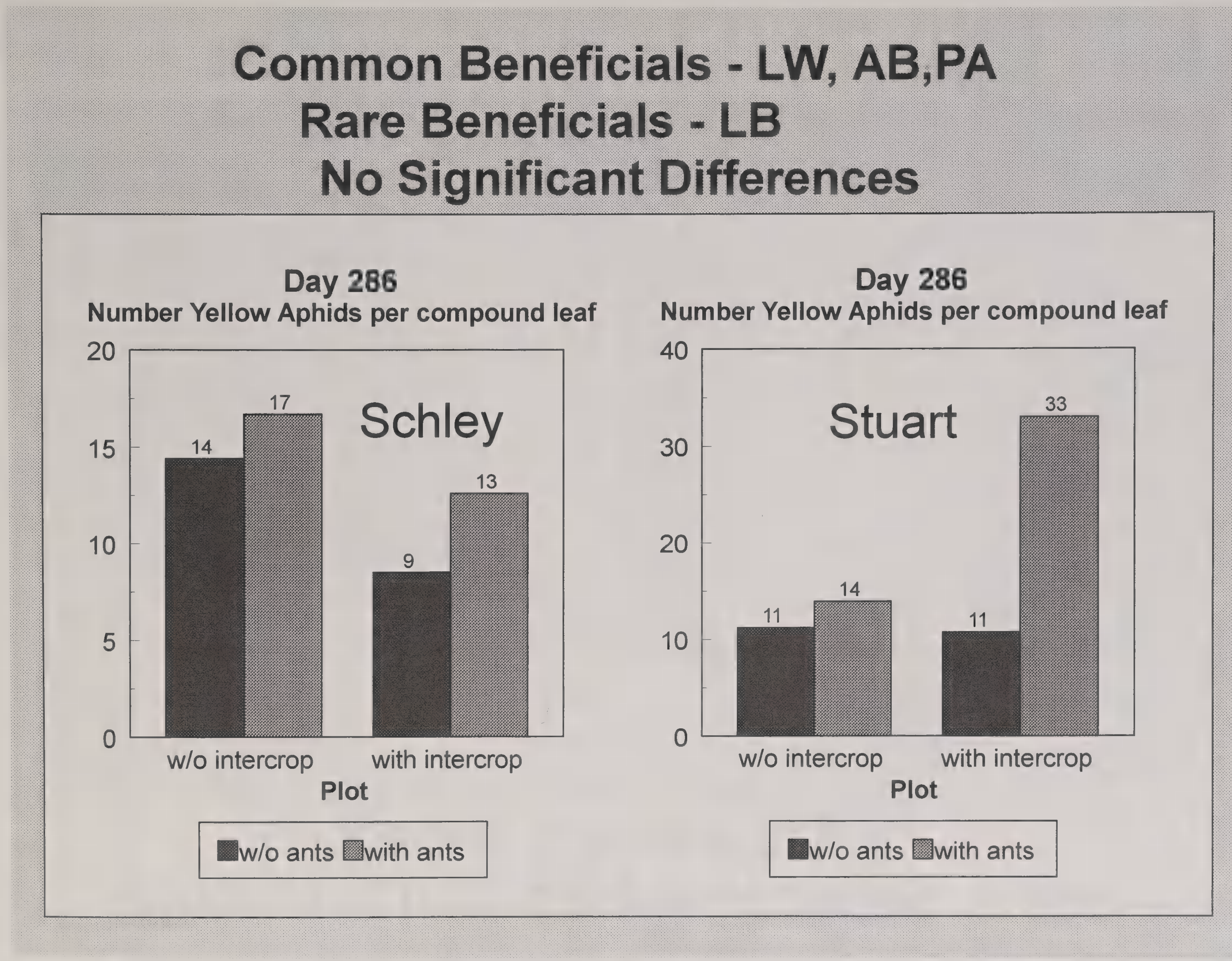

Common Beneficials - LW, AB,PA
Rare Beneficials - LB
No Significant Differences
Day 286
Number Yellow Aphids per compound leaf
Schley
20
15
10
5
0
14
17
9
13
w/o intercrop
with intercrop
Plot
w/o ants
with ants
Day 286
Number Yellow Aphids per compound leaf
Stuart
40
30
20
10
0
11
14
11
33
w/o intercrop
with intercrop
Plot
w/o ants
with ants

Figure 11

When are Intercrops Growing in the Pecan Understory ?

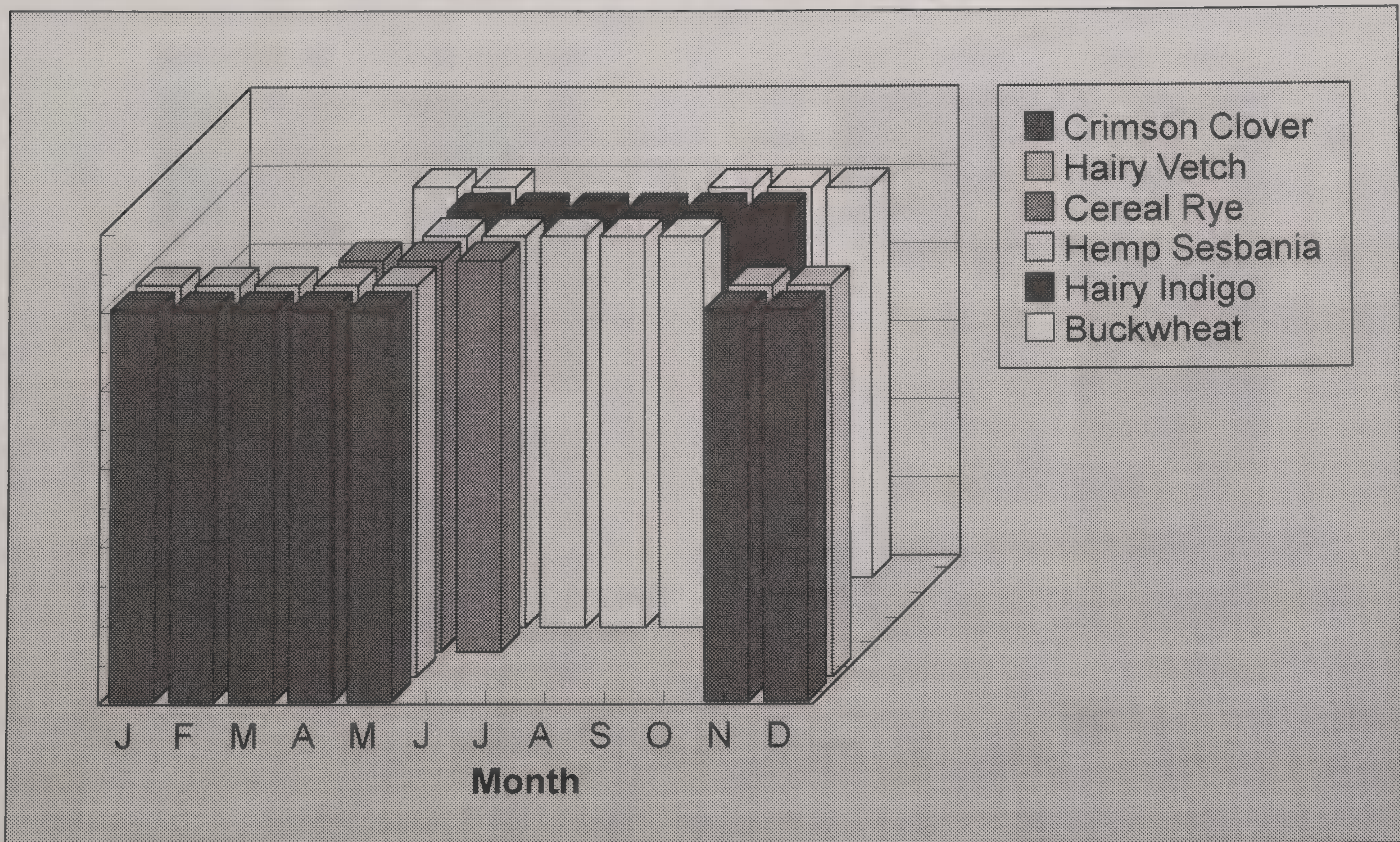


Figure 12

OVERVIEW OF PEST MANAGEMENT IN THE WEST

B. Ree[1]

ABSTRACT

The major arthropod pests in the western pecan producing states of Texas, New Mexico, Arizona and California include the pecan nut casebearer, *Acrobasis nuxvorella* Neunzig, hickory shuckworm, *Cydia caryana* (Fitch), pecan weevil, *Curculio caryae* (Horn), blackmargined aphid, *Monellia caryella* (Fitch), yellow pecan aphid, *Monelliopsis pecanis* Bissel, and the black pecan aphid, *Melanocallis caryaefoliae* (Davis). Several species of kernel feeding hemipterans can also cause significant losses but losses are more localized on an orchard by orchard basis rather than wide spread.

The nut infesting insects, pecan nut casebearer, hickory shuckworm and pecan weevil are not known to occur in Arizona or California. The pecan weevil is only found in portions of Texas.

Pest management practices available to producers in addition to insecticides include prediction and sampling models, economic thresholds, pheromone traps habitat management, adult emergence traps and trap crops.

INTRODUCTION

The pecan *Carya illinoensis* (Wang.) K. Koch is considered to be the most important horticultural plant indigenous to the United States (Brison 1974). The pecan is native to North America from the Mississippi River Valley to West Texas and into Mexico. Commercial production has expanded from this range to extend from the Carolinas across the southern and midwestern states to California.

Across this production range the there is a variation of pest complexes that attack pecan. In the western states of Texas, New Mexico, Arizona and California most of the nut infesting insects are restricted to Texas and recently a portion of southeastern New Mexico. Management strategies for the major insect pests in the west will be discussed.

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MAJOR INSECT PESTS

Pecan Nut Casebearer. Management strategies in Texas for the pecan nut casebearer, *A. nuxvorella* Neunzig are based upon monitoring degree days, pest populations and adhering to treatment thresholds.

A degree day model (Ring and Harris 1983) was developed to monitor biological events of the casebearer. With the degree day model, nut entry by the first summer generation can be anticipated and scouting activities planned. To complement the degree day model, which runs independent of pest populations, a sequential sampling model has also been developed that allows IPM decisions to be made quickly and precisely (Ring et al. 1989). With the sequential sampling model a treatment decision can be made in the field.

In most years in Texas, insecticide applications for the first summer generation will be required to prevent an economic loss, however, in some years casebearer can be considered beneficial. Light infestations during years of heavy crop loads can have a desired thinning effect which in turn improves quality at harvest.

If damaging populations are present and treatments are necessary, product selection and timing of treatment are important. It is known that pyrethroid and carbaryl insecticides induce yellow aphid populations. This is thought to be due, at least in part to the elimination of their natural enemies.

Over the past three years insecticides containing *Bacillus thuringiensis* var. *kurstaki* have been evaluated for pecan nut casebearer control in several pecan producing states.

Products containing Bt. have looked promising in past trials. Because Bt. products are nontoxic to natural enemies and pose minimal danger to the applicator, these products will be an important tool for a pecan IPM program.

Hickory Shuckworm. Until 1991 the hickory shuckworm was only found in Texas. In 1992 shuckworm was confirmed in Dona Ana County, New Mexico (Davis 1993).

Management for the hickory shuckworm *C. caryana* (Fitch) in Texas is not as refined as that for the pecan nut casebearer. Treatment decisions are based on previous history of damage and applications of insecticides are applied according to a crop development stage referred to as half shell hardening.

A pheromone that attracts male moths has been developed to monitor adult activity (Smith et al. 1987), however, in Texas treatment thresholds have not been established that relate trap catches to injury levels and treatment times.

Insecticides used for the hickory shuckworm are organophosphate, pyrethroid and carbaryl classes. Because of the biology and habits of shuckworm larvae the Bt. insecticides are not recommended.

Pecan Weevil. The distribution of the pecan weevil in the western states is limited 123 counties in northern, central and south central Texas (Harris 1979) (Fig. 1). The pecan weevil was detected during the winter of 1969-70 in Tularosa, New Mexico but was declared eradicated in 1976 (Nielsen and Harris 1992).

Pecan weevil management in Texas is directed at reducing larval populations within an orchard by preventing adult females from ovipositing in pecans (Harris et al. 1980). To accomplish this producers are encouraged to: monitor adult emergence, kernel development and soil hardness, and use carbaryl insecticide.

Numerous methods of monitoring adult activity have been developed (Neel and Shepard 1976), however, the wire cone trap is considered the standard. A new trap panel or silhouette trap developed at the USDA Fruit and Tree Nut Lab in Byron, Georgia, has look very good in trials and will offer producers another monitoring method. Treatment thresholds for the new trap have not been established at this time.

The monitoring of soil hardness is important in determining if there will be a drought delayed emergence (Harris and Ring 1980).

Pecan weevil management in Texas consists of: adult emergence traps which should be in place by early August; monitoring kernel development of the earliest maturing varieties to determine when the earliest maturing varieties will be susceptible to oviposition; the first insecticide treatment of carbaryl is applied around August 22 or once the earliest maturing varieties reach the gel stage.

If weevils are being caught in emergence traps five days after the first application, a second application is applied in 10 days after the first treatment. If traps are not collecting weevils after the first application the second application is delayed until weevils are collected. This will generally be after a soaking rain or irrigation. Traps should be monitored after the second application to detect any delayed emergence.

Records on application dates, rainfall, crop loads and weevil infestations levels should be recorded every season. A history of management activities will allow a producer to anticipate weevil activity for the coming season and evaluate the success or failure of his/her management program.

Kernel Feeding Hemipterans. Although problems with kernel feeding hemipterans are not as wide spread as other nut infesting insects, several species of stink bugs and leaffooted bugs can cause economic losses.

Some of the problems associated with stink bugs and leaffooted burs are: they are difficult to monitor in the pecan canopy; damage can go undetected until pecans are marketed and there are no established treatment thresholds. One method of monitoring or controlling this group of insects, is through the use of trap crops (Ree 1992).

Trap cropping can be defined as the planting of a very desirable host to attract a specific insect where it can be monitored or controlled. In pecans, small plots of purple hull peas have been planted in or near an orchard to attract the southern green stink bug, *Nezara viridula* (Linnaeus) and the leaffooted bugs *Leptoglossus phyllopus* (L.) and *L. oppositus* during September and October.

When populations of stink bugs/leaffooted bugs are detected in the trap crops, the small plots can be treated thereby reducing stink bug and leaffooted bug populations without treating an entire orchard.

Yellow Pecan Aphids. The consistent use of insecticides for the yellow aphid complex, *M. caryella* (Fitch) *M. pecanis* Bissel, has not proven to be effective across the pecan belt. Evidence of this has been seen in the southeast as well as in the Mesilla Valley of New Mexico (Anon. 1989).

Natural enemies have been shown to be an important factor in maintaining yellow aphid populations (Liao et al. 1984). Producers can utilize natural enemies in pecan orchards through several different ways.

Natural enemies can be conserved through the judicious use of insecticides; lacewings and lady beetles can be commercially purchased for augmentative release and the environment in the orchard can be manipulated through the planting of cover crops to enhance populations. Both warm and cool season cover crops have been investigated for increasing natural enemy populations in pecan orchards (Bugg and Dutcher 1989, Tedders 1983).

With the emergence of Bt. based insecticide in the pecan industry for casebearer management, the combination of these products with other management practices (cover crops, augmentative releases) may be an important tool in yellow aphid management.

Black Pecan Aphids. The consistent production of pecans can be directly related to the condition of the foliage the previous year therefore control of foliage feeding pests such as the black pecan aphid is important. Because black aphids

can cause significant amount of damage at low levels close monitoring of populations during August and September is required.

Management of economically damaging populations of black aphids will require insecticide applications. The treatment threshold in Texas is three per compound leaf.

SUMMARY

Other management options are available to producers and should be considered. Sanitation, trapping, habitat management, pheromones and mechanical and biological control are all viable means to producers and should be incorporated into a management program where possible.

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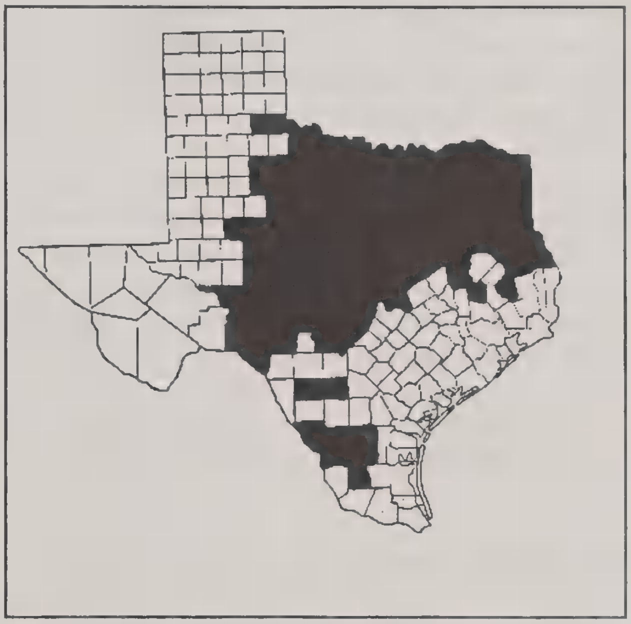

Figure 1. Pecan weevil distriubtion in Texas-1979.

PECAN NUT CASEBEARER UPDATE

M.K. Harris[1], J.A. Jackman[2], B. Ree[3] and A. Knutson[4]

ABSTRACT

Pecan nut casebearer management is the key to conserving natural enemies and using biointensive IPM in pecan throughout the early season. The GIS map allows anticipation of potentially damaging densities and facilitates appropriate assessment in making a management decision. If treatment is deemed necessary, the *B.t.* option allows additional flexibility in conserving natural enemies. The advent of a PNC sex pheromone provides a new tool for model confirmation, PNC monitoring and perhaps PNC management. These new improvements in PNC research provide opportunities for increased development and adoption of biointensive IPM in pecan.

INTRODUCTION

The integrated pest management (IPM) of pecan throughout the indigenous range (see Figure 1 in Harris 1983) is keyed to conservation of natural enemies of pests especially during the early season (Harris 1983, 1991). The judicious use of carefully selected insecticides and the avoidance of other disruptive chemicals (like sulfur) from budbreak in March until late August generally allows natural enemies to adequately control aphids, mites and leafminers. Late season management of hickory shuckworm, *Cydia caryana* (Fitch) (Lepidoptera: Tortricidae), pecan weevil, *Curculio caryae* (Horn) (Coleoptera: Curculionidae), stink bugs, (various coreids and pentatomids) and black pecan aphid *Melanocallis caryaefoliae* (Davis) (Homoptera: Aphididae) from August-November may require two or more treatments with chemicals highly toxic to natural enemies but are deemed unavoidable when damaging densities of these pests are found or anticipated based on past damage (Harris 1991).

This update addresses early-season pecan management approaches in Texas centered on pecan nut casebearer, *Acrobasis nuxvorella* Neunzig (Lepidoptera: Pyralidae). Experience has shown that one well-timed insecticide application, only if needed, for this pest can result in this being the sole insecticide treatment decision from budbreak to August (Harris 1991).

PNC BIOLOGY AND DISTRIBUTION

The pecan nut casebearer (PNC) is a monophagous, multivoltine nut feeder of pecan and commonly occurs in damaging numbers each year from northern Mexico and Carlsbad, New Mexico on the South and West to the Mississippi River valley on the North and East. Damage seldom occurs from this pest in the southeastern US (McVay and Ellis 1979) and a recent introduction to El Paso, Texas found in August 1988 has spread about 15 km in radius, but as yet has not damaged commercial pecans. The PNC overwinters as a small larva in a hibernaculum at the base of a dormant pecan bud. The larva becomes active at budbreak and grows and develops by tunneling in buds and shoots. Following pupation and mating, the overwintering generation females begin laying first summer generation eggs on the recently pollinated pecan nutlets. Larvae of the summer generations feed on nuts, and the first summer generation generally causes the greatest damage. Nut inspection for eggs and nut entry by larvae is the common monitoring method, and the action level for Texas (1% nut clusters infested) gives the proper timing for a single insecticide treatment if economic damage is to be prevented. A PNC degree-day prediction model has been developed, verified, generalized, and implemented to reduce time spent in field scouting while improving timing of treatment. This model has also been incorporated with a sequential sampling plan to make spray decisions (Ring et al. 1989).

UPDATE

There are three new improvements to PNC management that have been developed in the past few years. The first is a geographic information systems (GIS) generated map showing when management of first summer generation PNC should be undertaken if it is needed (Figure 1). This map is an interpolation of point predictions using the PNC model driven by daily weather data from about 90 National Weather Service weather stations across the southwestern U.S. The map is updated weekly and, of course, the more real-time weather used to construct the prediction the closer the prediction is expected to be to the actual event that will be observed. The map replaces the table listing towns where the same weather stations were used to make point predictions of the management date (Harris et al. 1989). The map provides an easy visualization of the same data.

The second improvement is the emerging data that indicate *Bacillus thuringiensis* endotoxins provide adequate management of borderline to intermediate (anticipated infestations of 10-40% or so of nut clusters) damage from PNC. The use of *B.t.* materials further conserves natural enemies and further reduces the risk of inducing secondary

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pests. We attribute this new found efficacy of these materials to industry development of more highly toxic *B.t.* strains formulated to increase longevity (i.e., slower degradation from ultraviolet light) combined with improved timing of application obtained using the PNC model and an increased tolerance by growers to accepting some PNC infestation (up to 10% of nut clusters) in a trade off for conserving natural enemies and thereby avoiding one or more additional applications during the summer period for secondary pests. The successful incorporation of *B.t.* for PNC can result in no broad spectrum insecticide use in the early season that disrupts natural enemies and allow natural biological controls to operate unhindered until at least August.

The third improvement is the development of a PNC sex pheromone under the leadership of Allen Knutson. Pheromone field trials using synthetic formulations successfully caught third summer generation males beginning in August 1993 and continues to capture first and second generation males in 1994. Presently, the most promising lure is comprised of a single chemical and captures males in standard sticky traps even in situations where nut inspection does not reveal the presence of PNC. The phenologies of the first and second summer generations in 1994 shows distinct generations that also correspond to the PNC model predictions that anticipate adult activity of the first summer generation. We anticipate field trials being completed during 1994 that will standardize a pheromone formulation that will become available for more widespread experimentation as a monitoring device in 1995.

The potential uses of the PNC pheromone are many and only a few will be mentioned here. The PNC model can theoretically predict biological events, including first summer generation PNC male adult activity and by extrapolation, nut entry, etc., with a time scale of hours. Obtaining field confirmation of these predictions has relied upon monitoring technologies that are very time-consuming and yield data that vary in days (nut inspection, banding for pupae, etc.). The PNC pheromone could provide an easier and more accurate test of the model prediction and allow adjustments to be made to improve the model. The monitoring value is also important, especially for second summer generation management decisions that are currently programmed to occur six weeks after first summer generation decision making. There is also the potential that second summer generation male moth density may be incorporated into an economic threshold. Current monitoring techniques using nut inspection for second generation are cumbersome and time-consuming and would be improved greatly, if replaceable by this pheromone technology. There is also the possibility of ecological studies in various pecan habitats to examine dispersal/ migration and suppression/eradication approaches where the PNC pheromone may be useful. These uses await further research.

ACKNOWLEDGMENT

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Table 1. Consolidation of pesticide trials data examining efficacy against pecan nut casebearer, *Acrobasis nuxvorella* in 1994. El Paso treatment applied May 23, 1994 using a 25 gal. capacity hydraulic hand sprayer sprayed to runoff. Washington County (10 miles east of Brenham, TX) treatments applied May 12, 1994 using an air blast sprayer delivering 80 gal. (= 4X) of finished spray/acre.

Location/Treatment/Rate (FM)	Pre-treatment Infestation	Post-treatment[a/] Cluster Infestation	Percent Reduction (Trt.+ check x 100-100)
El Paso (post-treatment inspection made June 13, 1994)			
Dipel ES-NT 1 pt./A	5%	8%	80%
Untreated check	4%	40%	N/A
Washington County (post-treatment inspection May 23, 1994)	28%	10%	45%
Dipel ES-NT 1.5 pts./A	16%	7.5%	58%
Javelin WG 1 lb./A	24%	16%	11%
Agree lb./A	32%	1.5%	92%
Lorsban 1.5 pts./A	36%	18%	N/A
Untreated check			

[a/] Both orchards had good nut set and check plots sustained economic damage. All Treatments except Agree suppressed PNC to or below the 10% cluster infestation level established as minimum acceptable control threshold.

UPDATE ON PECAN WEEVIL

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Additional index words. *Curculio caryae*, pyramidal, trap, monitoring system, visual attraction

ABSTRACT

An inexpensive pyramidal-shaped trap constructed of masonite and a boll weevil eradication trap top effectively monitored the emergence of pecan weevil adults, *Curculio caryae* Horn. Weevils were preferentially attracted to brown pyramidal traps when traps were painted brown vs. white. Brown traps positioned adjacent to trees having whitewashed trunks captured more weevils than the same traps adjacent to non- whitewashed trees. Tall pyramidal traps captured more weevils than short pyramidal traps having the same surface area. Two pyramidal traps/tree captured twice as many weevils as one trap/tree. Black pyramidal traps (1% reflectance) and dark gray ones (5% reflectance) captured more weevils than traps painted 6 lighter shades of gray (11, 18, 25, 37, 44, and 66% reflectance) and white (84% reflectance). There was no significant difference between capture by 1% and 5% reflectance traps. Five percent reflectance pyramidal traps (dark gray) captured almost 9 fold more weevils than did standard cone emergence cages. Dark gray traps captured weevils after the emergence period as determined by cone emergence traps. Weevil capture by dark gray traps located 1.9 and 4.6 m distance from tree trunks were not significantly different. Four dark gray pyramidal traps/tree did not provide control of weevils. Dark gray traps positioned on the eastern side of trees caught significantly more weevils than traps on the northern side of trees.

The pecan weevil, *Curculio caryae* (Horn), is a major pest of pecan trees in the U.S. and its control requires extensive use of chemical pesticides if the population is greater than a few individuals per tree. Pecan weevils are effectively controlled with insecticide, but control disrupts the orchard ecosystem and leads to major outbreaks of aphids and mites (Dutcher and Payne 1983). The need to effectively control weevil populations without excessive disruption of the ecosystem requires that there be an effective and practical means of monitoring weevil emergence. A number of monitoring methods have been used but each has met with varied acceptance. These methods include limb jarring, various tree-trunk trap bands, pyrethrum knock-down sprays, pheromone traps, and ground cover traps (Neel and Shepard 1976). The most recently developed method was a malaise trap for installation on the crotch of a tree (Dutcher et al. 1986). None of these methods seem to be accepted by the majority of growers having a serious problem with detection of weevils.

Important requirements for a practical and efficient trap for monitoring the appearance of pecan weevil adults are: a) sensitivity in detecting weevil presence; b) acceptable costs for construction and operation; c) convenience of installation, use, and storage; and d) acceptance by the grower. This paper describes a new trap that may satisfy these requirements. Also included is a chronological account of experiments from 1990 to 1993 with the trap and the results.

METHODS AND MATERIALS

We hypothesized that pecan weevil adults, upon emergence from the soil, were attracted to dark tree trunks which they visually observed. This seemed to be logical because weevils are secretive insects, they are frequently found beneath flakes of bark on tree trunks, they accumulate beneath burlap bands used by some growers for monitoring weevil presence (Tedders 1974), and it has been shown that 84% of weevils either fly or crawl to the tree trunk (Raney and Eikenbary 1968). With this information in mind we devised a trap base that conceivably could mimic the trunks of a tree (Tedders and Wood 1994, 1995).

The trap base was constructed of two triangular pieces of 0.64 cm thick tempered masonite board, each measuring 53.3 cm base x 121.8 cm height. One triangular piece was partially bisected with a 0.48 cm wide vertical saw-cut from the apex to one-half way to the base. The second piece of masonite was partially bisected with a 0.48 cm wide vertical saw-cut from the center of the base to one-half way to the apex. The two triangular pieces were then interlocked, utilizing the vertical bisects, to form a free-standing pyramidal shaped base. The pyramidal base was then painted with white or dark colored paint as required by each experiment. Boll weevil collecting trap tops (Anonymous 1990) were used on top of the pyramid for capturing weevils that were attracted to the base and that crawled upward on the base. The collecting trap tops were modified by enlarging the entrance hole to 0.95 cm diam.

We used whitewash (Anderson and Roth 1923) to paint or increase the reflective surface, of the tree trunks. Whitewash was sprayed on with a Hypro p.t.o. pump (New Brighton, MN) powered by a 5- Hp Briggs & Stratton gasoline engine. The pump was adapted with a hand-held John Bean Spraymiser gun having a No. 4 orifice disc. From 4 to 6 liters of whitewash was required to cover the trunk and lower part of scaffold limbs of 75- year-old trees to a height of 2.1-2.4 m.

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The degree of light reflected by pyramidal trap bases and tree trunks was estimated from a reflectance curve developed from known standards (Eastman Kodak Co., Inc., Rochester, NY) and measured in the laboratory with a Gossen Lunasix electronic exposure meter (P. Gossen and Co. GMBH, Erlangen, Germany) under constant lighting conditions. Lighting for measurements was by one BCA No. 1 GE incandescent photoflood lamp (General Electric Co., Cleveland, OH) backed by a 28-cm aluminum reflector. The bulb and reflector were positioned at 30_ from perpendicular center and at 25.5 cm distance from the subject. Minor illumination was provided by an overhead fluorescent lighting system. Total incident light measurement at the subject was 2200 Lux. Exposure meter measurements of light reflected by 4.5 cm^2 painted swatches of masonite were then easily converted to percent reflected light. Bark was removed from the trunks of whitewashed and natural trees, returned to the laboratory, and cut into several 4.5-cm^3 pieces. These were similarly measured and the values calculated for percent reflected light. Natural bark averaged 12 to 17%. Whitewashed pecan bark reflected about 84% of the light.

Trees used in the experiments were either 'Schley' or 'Stuart' cv. and were about 75-years-old. Unless otherwise stated the test orchards had received no insecticide for at least 10 years. The experiments were conducted from the last week of July until the last week of October of 1990-1993. Traps were examined for capture of weevils every 2 or 3 days.

Test 1. This study was initiated to evaluate the relative effectiveness of dark brown (5%) and white (84%) trap bases for attracting weevils. A brown trap and a white trap were randomly placed on opposite sides of a 75-year-old tree at ca. 3 m from the trunk. The location of the two traps relative to compass direction was random. The experimental design consisted of two trap color treatments (brown vs. white) structured as a randomized complete block with five single tree blocks. The total weevil count was then statistically analyzed by ANOVA.

Test 2. A second test was conducted to better understand the reaction of weevils to brown- and white-painted surfaces. We compared the number of weevils captured in a brown trap placed adjacent to a white-painted tree trunk with the number captured in a brown trap placed adjacent to the trunk of an unpainted tree.

We also decided to test an additional variable where the bases of traps were of different shapes but having the same surface area (tall vs. short). Bases of short traps were pentagons measuring 61 cm base x 91.4 cm height. The same brown and white paints of Test 1 were used.

Experimental design was a 2 x 2 factorial having 10 trees per treatment structured in a randomized complete block design. The four treatments were tall trap - natural tree (unpainted); tall trap - whitewashed tree; short trap - natural tree; short trap - whitewashed tree. One trap per tree was placed approximately 2.4 m from the tree trunk. Traps were placed at random on either the eastern or western side of the tree trunk (tree row) where grass had been removed by herbicide. Data analysis was for total counts per study period.

Test 3. A test was conducted to determine if one brown trap per tree would catch more or less weevils than two traps per tree, on a catch per trap basis. Experimental design consisted of two treatments in a randomized complete block design with six blocks. Treatments were one brown trap (A) per whitewashed tree and two brown traps (B) per whitewashed tree. Trap location and whitewash were the same as that described for Test 2. The location of trap A under a tree was randomly selected for either the eastern or western side. Where two traps (B) were used, one was placed on each side of the tree and at the same distances as for A. Data were analyzed by use of a *t*-test of the means.

Test 4. A study was designed to evaluate the attraction response of weevils to trap bases painted black (1% reflectance), seven shades of gray (5, 11, 18, 25, 37, 44, and 66% reflectance) and white (84% reflectance). One trap of each color (9 traps) was placed at random in a circle surrounding each tree. Traps forming the circle were at 40° and 3.9 m distances from the center of the tree trunk; thus, traps were 2.6 m (center to center) apart. Trunks of all trees were whitewashed to a height of about 2.1 m. The experimental design was a randomized complete block with ten single tree blocks. Counts of observations of the mean numbers of males, females, and males plus females/trap were statistically analyzed by SAS-ANOVA.

Test 5. A study was designed to compare the sampling efficiency of dark gray pyramidal traps (5%) with that of cone emergence traps. Cone traps were of the design recommended by the Georgia Cooperative Extension Service (Ellis and Hudson 1993-1994). The experiment compared the capture of weevils by twelve cone traps/tree with capture by four pyramidal traps/tree. The trunks of trees with pyramidal traps were whitewashed and the trunks with cone traps were left natural. Experimental design was a randomized complete block with 10 blocks. For the cone traps treatment, three of the 12 traps were placed in line on each cardinal direction and located at 1.2, 2.4, and 3.7 m distances from the trunk. For the pyramidal traps treatment, one trap was placed on each cardinal direction, each 1.8 m distance from the trunk. The orchard was comprised of trees having canopy radii averaging 8.3 m. Weevils in this orchard has been controlled with insecticides in accordance with the Georgia Cooperative Extension Service recommendations (Ellis et al. 1992) for several years prior to the experiment. The weevil population was known to be small and typical of most commercial orchards. Insecticide

was not used in the orchard during 1991. The grass and weed sod within the test area was first mowed and then herbicided with one application of glyphosphate (9.03 kg ai/ha)14 days prior to the initiation of the test. One-hundred nuts were randomly taken from each tree at harvest and examined for larval infestation. Because cone and pyramidal traps were positioned in the four cardinal directions, trap catches of weevils also were evaluated for the effect of direction. In addition, catches by cone traps were evaluated for the effect of distances from the tree. Counts of mean numbers of captured males, females, and males plus female weevils/treatment and infested nuts/ treatment were statistically analyzed by SAS-ANOVA.

Test 6. This test was designed to compare the effect of distance of dark gray pyramidal traps (5%) from the tree trunk on weevil capture. Treatments were one trap located 1.8 m from the tree trunk compared with one trap located 4.6 m from the trunk of an adjacent tree. Canopy radii of trees averaged 9.2 m. All traps were placed on the southeastern side of trees on the herbicided tree row strips. Tree trunks of both treatments were whitewashed. The test was a randomized complete block design, of 10 blocks with single tree experimental units. Weevil numbers were known to be large. Counts of mean numbers of captured males, females, and males plus female weevils/treatment were statistically analyzed by SAS-ANOVA.

Test 7. This test was designed to determine if four gray pyramidal traps (5%) surrounding a tree could provide measurable weevil control. For the first treatment, four traps were stationed under each tree; each at 2.4 m distance from the trunk on the northern, southern, eastern, and western sides. The tree trunks were whitewashed. For the second treatment, traps were not used but tree trunks were whitewashed. For treatment three, no traps or whitewash were used. Trees had a small set of nutlets. Grass and weed sod beneath trees was minimal due to heavy shade from the broad canopies of the trees ($\bar{x}$ radii=9.2 m). Weevil numbers in the orchard were large. The experimental design was a randomized complete block of 10 blocks and single trees were the basic experimental unit. One hundred nuts/tree were randomly collected and examined for larval infestation. The mean number of infested nuts/treatment and the numbers of captured weevils from each cardinal direction were statistically analyzed by SAS-ANOVA.

RESULTS AND DISCUSSION

Test 1. A total of 61 weevils (38 males, 23 females) were caught in the five brown traps and only 7 weevils (2 males, 5 females) were caught in the five white traps. When catches of both sexes are considered collectively, brown traps captured more weevils that did white traps ($\alpha \leq .05$). When the sexes were considered separately, the brown traps again caught more weevils than white ones ($\alpha \leq 0.10$). These data indicate that weevils are attracted to this type trap and that brown traps are more attractive than white traps in an orchard environment at the time of weevil emergence.

Test 2. Tall and short traps adjacent to whitewashed trees captured a total of 360 and 282 weevils, respectively, while tall and short traps adjacent to natural trees captured 144 each (Fig. 1). Fitting of quadratic regression equations to cumulative catches of male and female weevils and both sexes combined for each treatment throughout the trapping period indicated that treatment differences occurred (Fig. 2). Analysis of variance of the coefficient of linear regression on date of cumulative number of weevils captured per trap indicate that traps adjacent to whitewashed trees captured significantly more weevils than did traps adjacent to natural trees, and tall traps adjacent to whitewashed trees captured significantly more weevils than short traps adjacent to whitewashed trees. The reason that the tall traps captured more weevils than did short traps is not understood but may be related to the fact that a tall trap likely would be easier for a weevil in flight to see, due to its height. If males are more prone than females to fly, and if flight is above the short traps, then tall traps would likely be more effective at catching male weevils. We believe that this may have occurred. Also, the 44% females collected by the short traps is comparable to the 45% females reported from the closed cone trap collections by Dutcher et al. (1986) and which is believed to be near the true sex ratio for these weevils. There were no differences between tall and short traps adjacent to natural trees, but this would be expected because trees in these treatments were likely to be at least as attractive to the adults as were the traps.

Test 3. Means of data collected during this test were analyzed for males, for females, and for both sexes combined. Because Treatment A provided one sample per tree and Treatment B provided two samples per tree, the means of Treatment A were compared with one-half the means of Treatment B. Significant differences between the means of A and one-half of B were not detected for males, females, or both combined. Therefore, under these conditions two traps per tree would appear to capture twice as many weevils as one trap per tree, indicating that traps placed on opposite sides of a tree at these distances do not compete with each other.

Test 4. Total weevils captured in ten traps of each color were: 84% reflectance - 21 weevils, 66% - 28, 44% - 27, 37% - 56, 25% - 54, 18% - 101, 11% - 96, 5% - 220, and 1% - 200, for a total of 803 weevils (442 males - 361 females).

More male weevils were captured by black traps (1% reflectance; mean capture/trap 10.8) and by 5% reflectance traps. Captures of males decreased as trap reflectance increased. There was no significant difference ($\alpha \leq 0.05$) in

the number of males captured by a 1% reflectance trap as compared with 5% reflectance traps.

Most female were captured by dark gray traps (5% reflectance, mean capture/trap 11.5). Capture decreased as traps reflectance increased, but with a more gradual change than that observed for males. A dramatic increase ($\alpha \leq 0.05$) in capture was observed for traps reflecting 1% and 5% light, as compared with traps reflecting 11% or more light.

When captures of males and females combined were observed, there were obvious periodic decreases in captures as light reflectance of traps increased (Fig. 3). Mean capture/trap of 1% and 5% reflectance traps were 20 and 22 weevils, respectively, and these treatments were not significantly different ($\alpha \leq 0.05$). The stepwise nature of capture by traps with periodic change in reflectance indicates that the rates of change of trap reflectances used in this test did not always elicit difference in weevil response. Perhaps weevils were unable to detect differences in the levels of reflected light used in the test or perhaps the weevil population level was to small to allow for resolution of change at the reflectance levels. From this test we conclude that reflectance levels of 1-5% were best for best capturing weevils. We elected to utilize 5% gray traps for additional tests because traps of that reflectance captured more weevils.

Test 5. The first weevil found in cone emergence was on August 9 and the last was on September 20, indicating an emergence period spanning about 43 days (Fig. 4). More than 50% of emergence occurred between September 2 and 14 with major peaks in emergence on September 7 and 13. The September 7 peak was mostly females whereas the September 13 peak was mostly males. Peak emergence may not have been well defined due to the small numbers of captured weevils (α=0.38/trap). Ninety out of 120 cone traps (75%) failed to capture weevils. Sixty-one percent of weevils captured in cone traps were males.

The first weevil captured by dark gray pyramidal traps was also on August 9, and the last was on October 28, indicating an emergence period of about 63 days; about two weeks longer than that indicated by cone traps. Three peaks of weevil presence were indicated on August 16, September 1, and September 20. The largest peak was predominantly males and occurred about the same time as the last capture of weevils by cone traps. The largest peak of females occurred on August 16 but significant numbers of females also were captured after the last capture of females by cone traps. Pooled counts of weevils captured by all pyramidal traps was 136 (α=3.40/trap). Fifty-seven percent of weevils captured by pyramidal traps were males.

When comparing treatments (12 cone traps/tree vs. 4 pyramidal traps/tree), pyramidal traps captured 3.0 fold more weevils/trees than cone traps. When traps were compared on a 1 cone trap vs. 1 pyramidal trap basis, pyramidal traps captured 8.9 fold more weevils. Pyramidal traps captured significantly more weevils during and following the emergence period indicated by cone traps ($\alpha \leq 0.05$).

In this test, there was no directional effect ($\alpha \leq 0.05$) in number of weevils in cone traps based upon distance from the tree trunk. However, low numbers of weevils in this test may have masked these differences, if they exist.

Weevil infestation of nuts were not significantly different ($\alpha \leq 0.05$). Nuts from trees of the cone traps treatment averaged 14.8% infested and those of pyramidal traps averaged 12.5%.

Test 6. Average weevil capture/trap season was 66.2 at 1.8 m and 67.4 at 4.5 m and these were not significantly different ($\alpha \leq 0.05$). Indeed, there was an almost perfect overlap of the curves plotted for the traps of both distances (Fig. 5). Peaks of weevil capture were similar for all dates and mean numbers captured were also similar. The first peak occurred during August 6-28 and the second on September 13. Minor numbers of weevils were captured at both distances during October and November. More than 50% of all weevil captures occurred between August 30 and September 22. Weevils captured at 1.8 m and 4.6 m, were mostly males (58.7 and 58.2%, respectively).

Test 7. Substantial capture did not begin until August 9. Total weevil capture per 40 traps (10 replicates) was 2,107 (α=52.7/trap). Distinct peaks of capture occurred on August 13, September 7 and September 22. More than 50% of all weevils were captured during the period September 3-24. Of all weevils captured during the test, 59.7% were males.

The majority of nutlets on the test trees aborted during early August as a result of drought; thus we were unable to accurately assess the effect of traps for weevil control. The 100 nut samples from trees were randomly taken from nuts remaining on the tree and from aborted nuts on the ground. Most trees had only a few nuts remaining at harvest; thus feeding pressure on these few remaining nuts was high. Assessment of weevil injury resulting from feeding and oviposition revealed means of 76, 91, and 81% damage to nuts of natural trees, whitewashed trees, and whitewashed trees plus 4 traps, respectively; however, these means were not significantly different ($\alpha \leq 0.10$).

A direction effect of weevil capture by traps was evidenced in this experiment. Traps on the eastern side of trees captured a mean of 70 weevils/trap; those on the southern side - 56; western side - 48; and northern side - 36. Capture by traps on eastern and northern sides were significantly different ($\alpha \leq 0.05$; df=27; ms=960) but eastern and northern captures were not significantly different ($\alpha \leq .05$) than southern and western captures.

CONCLUSIONS

These experiments indicate that pyramidal traps offer a practical and efficient method for detecting the presence of weevils within pecan orchards. The primary concern by growers is the relative abundance of adult weevils in the pecan orchard at any given time and the potential for loss of nuts by a given weevil population. Pyramidal traps capture more weevils/trap and should provide users information about weevils over a longer period of time than do cone traps. Pyramidal traps are more sensitive for detecting small weevil populations.

These data indicate that the 1 or 5% gray pyramidal traps placed under trees with whitewashed trunks is superior to the standard cone emergence trapping system for capturing and monitoring adult weevils during and after the emergence period. The use of four pyramidal traps/tree did not exhibit evidence of weevil control by trapping the emerging individuals. For maximum effectiveness, the data indicate that traps should be preferentially positioned on the eastern side of whitewashed trees at distances from 1.8 m to one-half the canopy radius.

This research was based upon the premise that weevils are attracted to tree trunks reflecting low levels of visible light. Weevil responsiveness to low levels of light may also be dependent on background illumination. We believe that weevils perceive pyramidal traps as tree trunks and that they do not recognize whitewashed tree trunks as such. If these assumptions prove correct, then significant knowledge of the behavior of pecan weevils has been gained.

Further study with the pyramidal trap strategy is needed to define the optimum reflectance for maximum attraction of weevils, the role of color of light reflected by the trap, the influence of background illumination, the role of infrared radiation by traps, and the diurnal timing of weevil emergence from the soil.

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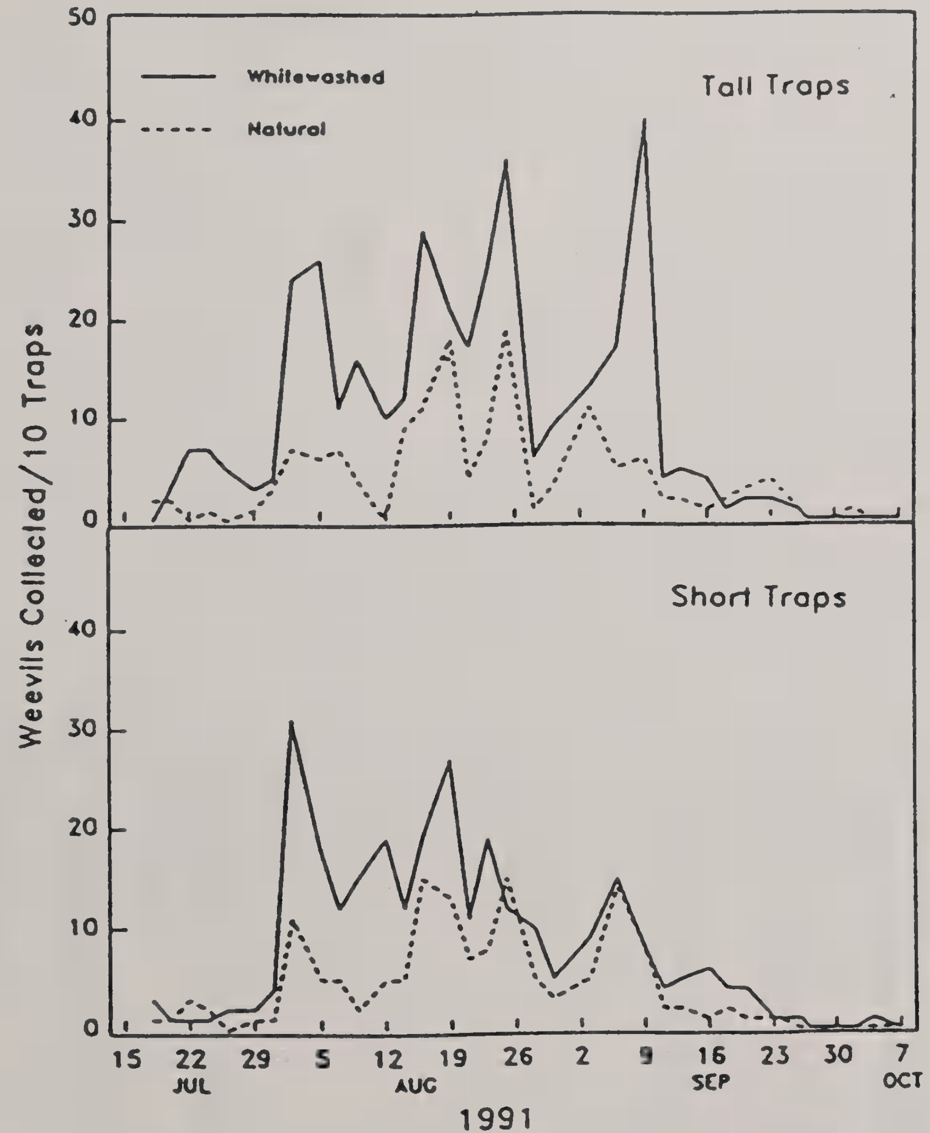

Figure 1. Total number of weevils collected by10 tall traps adjacent of whitewashed trees and 10 traps adjacent to natural trees, and number of weevils collected by 10 short traps placed adjacent to whitewashed trees and 10 traps adjacent to natural trees, 18 Jul-7 Oct 1991.

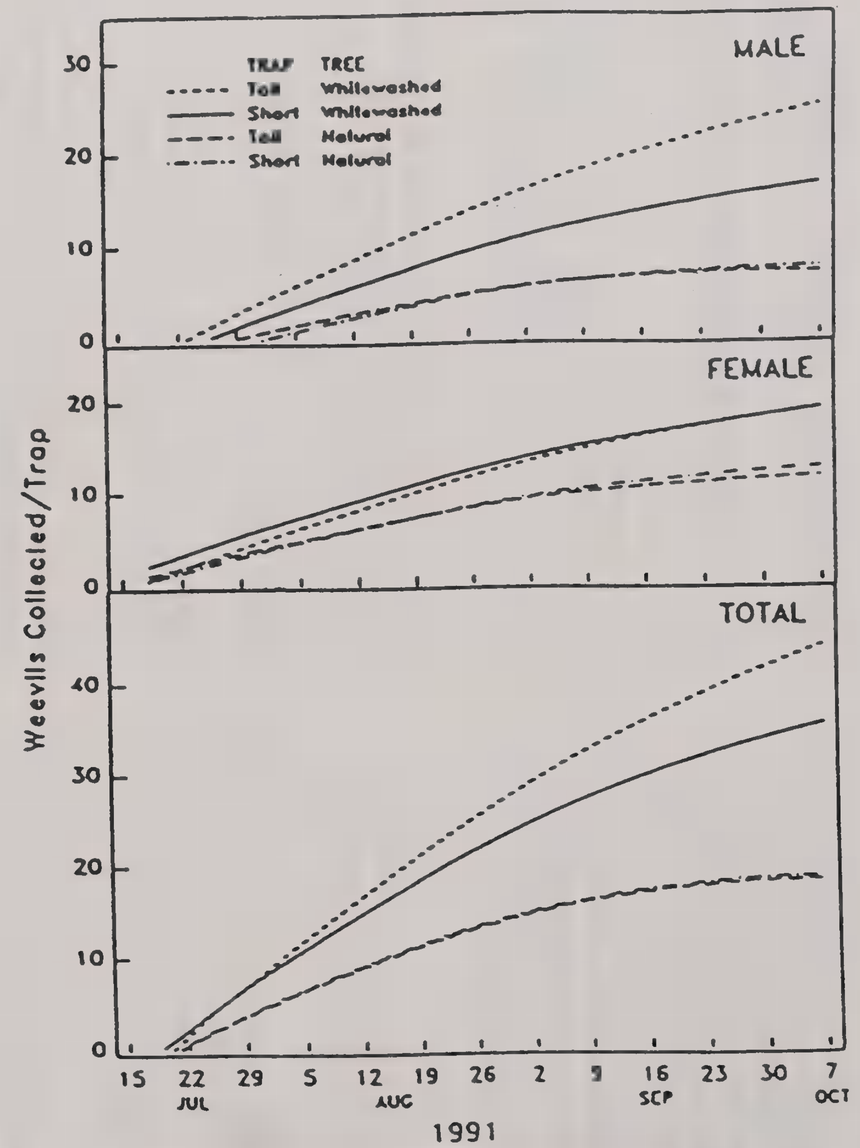

Figure 2. Linear regression of cumulative numbers of male weevils, of female weevils,and of male plus female weevils, collected by tall and short traps adjacent to whitewashed and natural trees, July-Oct 1991.

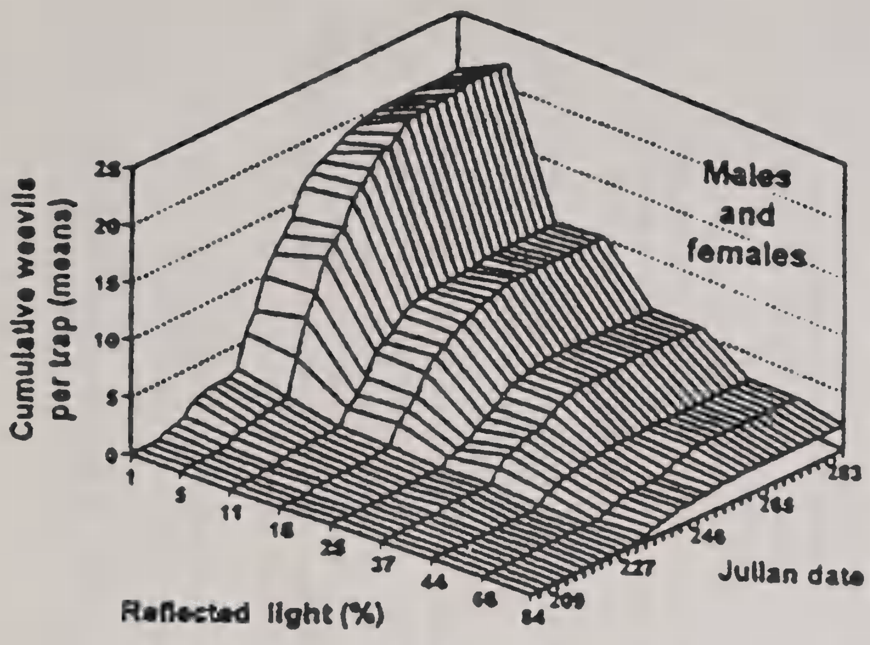

Figure 3. Graphs of cumulative pecan weevil capture (mean/trap), percent light reflected by pyramidal trap and date of weevil capture; July-October 1992, Byron, GA.

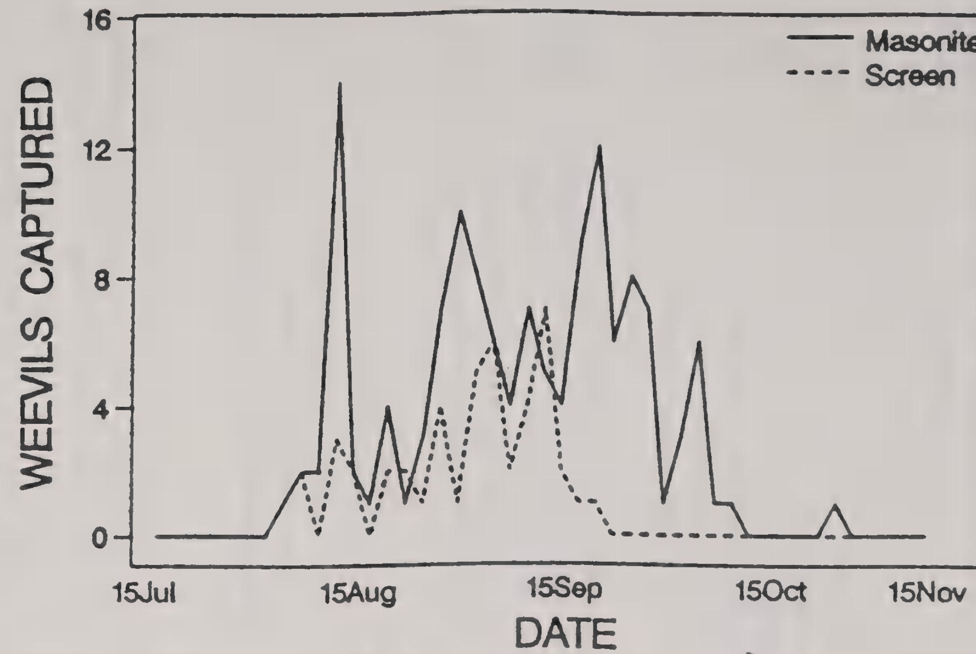

Figure 4. Total number of pecan weevils captured by 40 dark gray pyramidal traps compared with total weevils captured by 120 cone emergence traps, July-November 1992, Byron, GA.

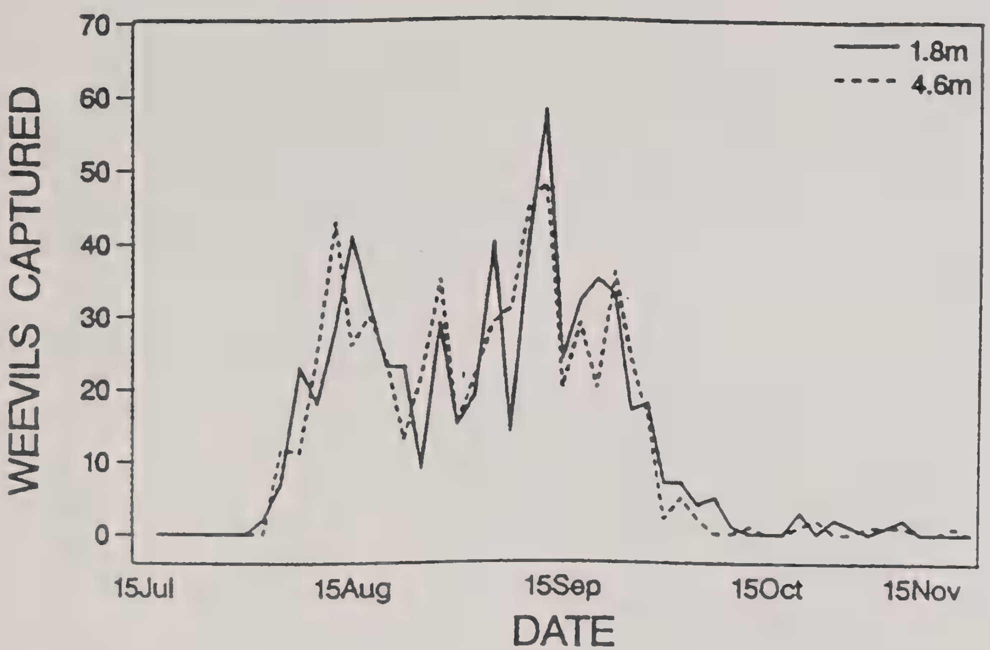

Figure 5. Mean number of weevils captured by pyramidal traps located 1.8 and 4.6 m distance from tree trunks, July-November 1992, Byron, GA.

APHID-HOST PLANT INTERACTIONS IN PECAN

M.T. Smith[1]

The blackmargined aphid, *Monellia caryella* (Fitch), yellow pecan aphid, *Monelliopsis pecanis* Bissell, and black pecan aphid, *Melanocallis caryaefoliae* (Davis), comprise the complex of aphid species infesting pecan, *Carya illinoensis* (Wang.) K. Koch, throughout the southeastern United States (Tedders 1978, Dutcher 1985). Interactions among these aphid species and their pecan host plants have been investigated primarily from the perspective of the effects of aphid feeding upon the pecan host. Expressions of these effects, which may be immediate, short-term, and/or long-term, include clogging of phloem tubes and disruption of translocation, loss of chlorophyll and suppression of photosynthesis, and reduced nut quality and production (Tedders and Wood 1985; Wood and Tedders 1982a, 1982b, 1986).

Because aphid-host plant interactions also involve the reciprocal effects of the host plant upon the aphid, earlier research from this perspective was largely observational and descriptive in nature, relying heavily upon monitoring of aphid densities on various pecan cultivars throughout the growing season. These observations are summarized in Table 1.

In recent years, however, quantitative evaluations of pecan aphid responses to various host plants are being conducted. In the first report of a systematic, phylogenetically-based approach, Smith and Severson (1992) compared the developmental biology and behavioral activity of *M. caryella* among four plant species; pecan, pea [*Pisum sativum* L.], fig [*Fiscus benjamina* L.], and peach [*Prunus persica* (L.)]. We concluded that *M. caryella* is restricted to the Juglandaceae family of nut trees, and provided evidence that its host plant specificity may be governed phytochemically.

Subsequently, biological performance and behavioral responsiveness of *M. caryella*, *M. pecanis*, and *M. caryaefoliae* among Juglandaceae species native to North American (including walnut, hickory and hican species) showed that Juglandaceae species most clearly related to pecan within the Apocarya (pecan hickories) were the preferred and/or most suitable host plants. Most Juglandaceae species were totally rejected as host plants (Smith et al. 1992; Smith et al. 1993).

Recently, Walid and Dutcher (1994) reported on the probing behavior and population density of all three pecan aphid species on a select group of 13-yr-old pecan cultivars. They have found varying degrees of preference and non-preference among cultivars (Table 2), and showed probing behavior on detached leaves to be correlated with aphid population density in the field. However, their probing behavior studies were only performed between 15 and 27 September, and aphid population density was only reported from early July and early October.

Finally, unpublished biological and behavioral studies of all three aphid species have been conducted with the added dimension of seasonal development of the Juglandaceae species and a select group of pecan cultivars. These evaluations were performed at regular time intervals over a given season and indicate that the degree of host acceptance/rejection of the various plant species changes over the plants' phenology. Further, ongoing comparative leaf chemical analyses indicate that various plant species may change phytochemically over the season. Comparative leaf morphological analyses (surface and interior) are also in progress.

The primary objective of these most recent aphid-host plant interaction studies has been to identify sources of aphid resistant germplasm. A combined result of these studies is to emphasize the importance of using more definitive methodology when evaluating sources and mechanisms of host plant resistance. Two of the three mechanisms of resistance include antibiosis and non-preference. Painter (1951) defines antibiosis as those adverse effects on insect life history which result when a resistant host plant variety or species is used for food. He defines non-preference as insect responses that lead to or away from the use of a particular plant or variety, for oviposition, for food, or for shelter, or for combinations of the three. Methodology used to evaluate antibiosis involves confining aphids on the various plants and measuring survival, development, and reproduction. Methodology used to evaluated non-preference involves placing aphids onto various plant types, and observing and measuring aphid response by various techniques. While aphid density on plants in the field may provide an indication of the plant's suitability as a host, factors unrelated to the plant (biotic and abiotic) also influence aphid population density and distribution. Therefore, conclusions of aphid resistance should not be based strictly upon field observations of aphid density, but should be supported with direct measurement of aphid biology and behavior.

Finally, the ongoing work by Smith, Severson, and Gueldner show the dynamic nature of the host plant's phytochemistry and aphid biology and behavior. Therefore, investigations of aphid-plant interactions should avoid the narrow view that the plant, serving as a food source, is a

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static unchanging entity, and take into account the dynamic nature of the host plant over a growing season.

The primary emphasis of current investigations is the identification of key phytochemical and/or morphological plant characteristics which control host plant resistance. Development of bioassays of these characteristics, as well as screening for their presence in various germplasms, are in progress. As new basic information is developed it will be utilized in pecan breeding, orchard design, and aphid resistance management programs.

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Table 1. Pecan Aphid Response to Various Pecan Cultivars Based Upon Observed Aphid Population Levels. (BPA=black pecan aphid; BMA=blackmargined aphid; YPA=yellow pecan aphid).

PECAN CULTIVAR	PECAN APHID	APHID RESPONSE	REFERENCE
Schley	BPA	Preferred	Moznette et. al. 1940
Alley	BPA	Preferred	Moznette et. al. 1940
Van Deman	BPA	Preferred	Moznette et. al. 1940
Stuart	BPA	Preferred	Moznette et. al. 1940
Gloria Grande	BPA	Susceptible	Madden 1972; Worley 1978
Peruque	BPA	Susceptible	Madden 1972; Worley 1978
Moneymaker	BPA	Escape	Moznette et. al. 1940
Curtis	BPA	Escape	Moznette et. al. 1940
Moore	BPA	Escape	Moznette et. al. 1940
Success	BPA	Tolerant	Nakayama 1964
Pawnee	BMA,YPA	Resistant	Thompson et. al. 1992

Table 2. Pecan Aphid Response to Various Pecan Cultivars Based Upon Behavioral Observations (Yellow Pecan Aphid includes both M. caryella and M. pecanis; Black Pecan Aphid refers to M. caryaefoliae) (Revised from Walid and Dutcher, 1994).

PECAN CULTIVAR		
YELLOW PECAN APHID	BLACK PECAN APHID	RELATIVE APHID APHID RESPONSE
Cheyenne	Oconee	Preferred
Shoshoni	Cheyenn	|
Tejas	Shoshoni	|
Oconee	Gloria Grande	|
Kiowa	Tejas	|
W. Schley	Kiowa	|
Gloria Grande	61-6-67	|
61-6-67	W. Schley	|
Cape Fear	Cape Fear	|
Pawnee	Pawnee	Non-Preferred

PECAN SCAB MANAGEMENT IN HUMID REGIONS

A.J. Latham[1]

ABSTRACT

In areas of frequent rainfall, i.e., highly humid environments, management of pecan scab may be centered around four basic premises. First, to develop quality pecan kernels during the production year, pecan leaves must be maintained in healthy, disease-free conditions to manufacture the nutrients needed by the growing nuts. Second, to develop carbohydrate reserves and set a crop of pecans the following year, pecan leaves must be maintained on their trees until at least 1 November. Third, to obtain maximum crop production, green nuts must be maintained disease-free. Fourth, applications of fungicides must be made in relation to frequent rainfall to effectively protect foliage and green nuts from the development of scab.

Scab caused by *Cladosporium caryigenum* (Ell. et Lang.) Gottwald (=*Fusicladium effusum*) (Gottwald 1982) is the most important disease of pecans (*Carya illinoensis* (Wang.) C. Koch) in humid areas such as the southeastern United States (Gottwald and Bertrand 1983, Latham 1982). To effectively manage pecan scab, researchers and growers must have a clear understanding of how *C. caryigenum* develops in pecan tissues, how it is influenced by environmental factors, and how effective are the control methods.

ETIOLOGY OF SCAB ON LEAVES

Cladosporium caryigenum overwinters in lesions, i.e., stromata on shucks, leaf petioles, and twigs infected the previous season (Demaree 1924, Gottwald and Bertrand 1982). In the spring, the conidiogenous stroma produce conidia that function as primary inoculum (Gottwald and Bertrand 1982, Latham 1982). As temperatures and wind increase in the morning, humidity decreases below the usual night-time condition of 100% RH, and conidiophores responding to drying conditions release their conidia. Populations of condia disseminated into the atmosphere increase to a peak at 1200 hr, according to aeobiology data (Gottwald and Bertrand 1982, Latham 1982). When a conidium falls onto a juvenile leaf moistened by free water, the conidium germinates and pecan tissues may become infected within 2-3 hr (Gottwald 1985, Latham and Rushing Infection of the leaf is by direct penetration. The pathogen colonizes leaf tissues subcuticularly and after 7 to 9 days incubation, breaks through the plant's cutivle to resume conidiation (Demaree 1928, Latham 1988). Continued discharge of conidia, and frequent rains may lead to successive infection periods that cause newly emerging leaves to become partially to totally covered by coalescing lesions of *C. caryigenum* (Gottwald and Bertrand 1988, Latham 1982). Scab on the foliage is especially important early in the season before nut set, since it serves as the inoculum base to infect the developing nutlets (Gottwald and Bertrand 1988). As pathogenesis continues, and the lesions mature, internal leaf cells collapse, leaflets become non-functional, and abscise from their rachis (Latham 1982, Latham and Rushing 1988). As a result, during unusually rainy years, trees may become defoliatated by mid-to late summer (Latham 1982).

Pecan leaves are susceptible to infection when they are young and actively growing (Gottwald 1985, Latham 1982, Latham and Rushing 1988, Payne et al. 1979). The susceptibility period of leaflets to *C. caryigenum*, lasts for approximately 7-21 days after bud break (Gottwald 1985). New compound leaf emergence along the elongating shoot and maturity of leaflets along the leaf rachis prolongs the time and number of susceptible leaves available for scab development (Latham 1979, Latham 1982). Therefore, during tree foliation, the over-all period of susceptibility to *C. caryigenum* may extend to 90 or more days (Latham 1979).

Thus, our first major concern relative to managing pecan scab:

1. To develop quality pecan kernels, during the production year, pecan leaves must be maintained in a healthy condition with an appropriate disease control program.

According to Worley (1979), pecan trees stressed by defoliation sustained reduced kernel percentages as the defoliation date became later from 1 August through 15 September. Nuts produced from trees defoliated during late summer were small and of poor quality (Gottwald and Bertrand 1988, Worley 1979). As a result of total defoliation in 1969, no yield of pecan nuts occurred during 1970 and 1971 (Worley 1979). Additional research by Worley (1979) showed that defoliation in the fall depleted carbohydrate reserves and reduced or prevented nut growth if defoliation occurred prior to 1 November.
Thus, our next major concern relative to managing pecan scab:

2. To develop carbohydrates for a crop of pecans the following year, pecan leaves must be maintained on trees until 1 November.

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ETIOLOGY OF SCAB ON NUTS

Pecan nut-shucks are only moderately susceptible for the first 2-3 weeks after nut set (Gottwald and Bertrand 1983). Gottwald and Bertrand (1988) reported that as soon as the nuts entered a rapid expansion or growth stage, susceptibility to scab increased. Accordingly, rates of scab increase appeared to accelerate in response to the increased susceptibility of the tissues (Gottwald and Bertrand 1988). They (Gottwald and Bertrand 1983 and 1988) concluded that during mid-to late-season, nut-shuck tissues again decreased in susceptibility as nuts ceased to expand and started to fill. The effects of *C. caryigenum* infection on nut quality were reported as the result of infection that occurred prior to mid-June, coincident with the time of shell (endocarp) differentiation (Gottwald and Bertrand 1983).

According to Shuhart (1932), who reviewed the morphology and anatomy of the fruit of *Carya illinoesis* Koch, the shuck is that portion of the fruit which dehisces from the nut at maturity and separates into four sections. Each section contains an outer ring of vascular bundles which provide for the flow of nutrients from the peduncle to near the distal end of the fruit. Subsequently, the course of the bundles crosses to the inner side of the shuck, and the direction of nutrient flow is reversed to proceed to the nut base then pass through a septum into the ovary. Calcote et al (1984) traced the vascular system of the shuck with acid fuchsin dye translocated through live tissues. This technique was used to study the effect of feeding and tunneling by hickory shuckworm larvae on the vascular bundles. Damage of shucks at the base of the fruit caused the nuts and kernels to weigh less than insect-free green nuts. They found a large portion of the vascular bundles leading into the ovary on the inside of green shucks had been severed near the base of the nut. These nuts were usually "pops"; i.e., shells devoid of edible kernels that resulted from tissues infested with larvae. In a similar manner, the pathological effects of *C. caryigenum* may damage vascular bundles and cut off the flow of nutrients to the developing ovary.

Preliminary investigations in our laboratory (Campbell and Latham 1993) have discovered mycelium of *C. caryigenum* occurred between sub-epidermal cells of Schley pecan shucks 24 days after inoculations. At 36 days, epidermal cells had collapsed and mycelia had penetrated 6-8 cells or more deep and toward the vascular system. We are continuing these host-parasite investigations to evaluate how scab affects the shuck tissue systems to reduce or stop nut maturation.

Thus, our next major concern relative to managing pecan scab:

3. To obtain maximum crop production, shucks of growing nuts must be maintained free of disease with appropriate disease controls.

EFFECT OF MOISTURE

Moisture in the form of rain, fog, or dew is required for successful infection of pecan tissues (Demaree 1924, Gottwald and Bertrand 1982, Latham 1982). The environmental factor driving the whole problem of scab on pecans is water.

Conidia (of *C. caryigenum*) + pecan tissue (susceptible) + H_20 ——> SCAB

In Oklahoma, Barnes (1974) demonstrated that three sprays of benomyl per season at 8-week intervals were sufficient to control scab on the cultivar Western during the dry 1972 growing season. During the more humid 1973 growing season, sprays at 4- and 6-week intervals provided commercial control of scab. Subsequently, Wells et al (1976) conducted scab control evaluations in the more humid growing area of central Georgia using the cultivars Schley and Stuart. During the severe scab year 1975, they found that benomyl at 0.1 lb and fentin hydroxide at 0.1 lb applied in 10 sprays gave commercial control on both cultivars. However, when the trees were sprayed only three times during the season, control of scab was not significantly different from unsprayed trees even though the fungicide rate was increased 50%.

During 1974 and 1975, Latham (1982 a,b) studied scab development in unsprayed pecan orchards near Auburn for a 15-week period from April to mid-July. Rainfall, humidity, temperature, wind speed, and leaf wetness were monitored. Conidia trapped with Kramer-Collins spore samplers during the 15-week periods of 1974 and 1975 totaled 23,406 and 63,349, respectively; rainfall recorded during these same periods was 20.4 cm and 44.3 cm, respectively. These comparisons of conidia and rainfall totals showed 270.7% more conidia and 217.2% more rainfall in 1975 than 1974. The peak number of conidia at the end of May 1975 was associated with an average of 300 lesions per compound leaf, which was a conservative count on leaves that were almost completely covered with lesions. Disease incidence became so high that trees defoliated from mid-July through August during the scab epidemic of 1975. Lesions produced on nuts were also recorded from 60 nutlets from 1 June through 12 July. Coalescence of lesions during the second week of July 1975 made accurate counts difficult. Nutlets shriveled, dried, and fell from trees until only 7 of the 60 nuts monitored for disease development were found on July 25.

Additionally, to directly study the effects of rainfall, Latham (1982a,b) used scab-free Schley pecan trees growing in individual plastic bags as "trap crop" or test trees. Six trees were inoculated with a calculated dilution of *C. caryigenum* and six were left uninoculated. The bagged trees were suspended from limbs under scabby foliage and at heights ranging from 6 to 18 ft. After exposure for 1 week, the test

trees were returned to the greenhouse and 12 new replacement trees were installed. Inoculated and uninoculated trees failed to develop scab on leaves during three periods when no rain fell, i.e. during the periods 29 May through 9 June, 9 June through 16, and July 7 through 14. All inoculated and uninoculated trees exposed for periods beginning 16, 23 and 30 June, a time when there was rain, developed scab. The amount of rain did not appear to be critical for infection and lesion development. The important criterion was hours of leaf wetness following rainfall. Scab developed on the test trees 7-9 days after a rainy day when leaves remained wet 12 to 16 hours.

Therefore, another major concern relative to managing pecan scab:

4. Fungicide applications must be made in relation to frequent rainfall to effectively protect foliage and nuts from infections by *C. caryigenum*.

CONTROL

In the humid Southeastern States, pecan nuts may become black from the coalescence of scab lesions on trees not protected with season-long fungicide applications; nuts fall prematurely, and a total loss of the crop occurs (Demaree 1924, Latham 1982). The basic, standard fungicide for control of pecan diseases has been fentin hydroxide (triphenyltin hydroxide, TPTH, Super Tin). Other fungicides used irregularly or in special situations are benomyl, dodine, and propiconazole. The Alabama Cooperative Extension Service scab control recommendations (Sikora and Goff 1994) advise a first spray application at budbreak. This is followed by three applications at 14-day intervals for: prepollination, pollination, and first cover. Subsequently, applications of fungicides are made at 21-day intervals until the end of August. During frequent rainy weather or in orchards containing cultivars that are quite scab-susceptible, the schedule may need to be closed-up to 10-14 day intervals. The full, recommended rates of TPTH should always be used throughout the spray period to prevent scab from becoming established. Also, thorough coverage of all of the tree by the fungicide spray is essential to keep both foliage and developing nuts healthy.

ADDITIONAL CONSIDERATIONS

Recommendations for establishing a new pecan orchard that were listed for the First National Pecan Workshop (Latham and Goff 1991) are still effective and should be reviewed before planting. Also, when selecting pecan cultivars, some consideration should be given to scab resistant selections. Although strains of *C. caryigenum* may develop and attack a previously resistant cultivar, most cultivars retain a degree of resistance that is of practical value to growers. For instance, at the Gulf Coast Substation, Ala. Agric. Exp. Stn., during the 1993 season, 23 pecan cultivars were maintained on the recommended scab control program with excellent results except for the highly scab-susceptible cultivars Cherokee and Cheyenne.

Maintain orchard sanitation, i.e., remove limbs, shucks, and other debris that may provide an inoculum base for fungi to grow and propagate diseases.

Keep the areas between tree rows known as "middles" mowed to reduce humidity, promote air flow through the orchard, and to enhance drying of foliage and fruit.

Information regarding the growth habit of a particular cultivar may also facilitate scab management. The Schley cultivar normally has one major and one or two subsequently less vigorous growth flushes per year (Gottwald and Bertrand 1988). As mentioned earlier, *C. caryigenum* only colonizes juvenile tissues, on which it produces conidia; however, as the leaves mature, they become resistant to infection. By comparison, Gottwald and Bertrand (1988), found the Wichita cultivar, tended to have numerous flushes of foliage throughout the season. These flushes of foliage provided a nearly continous supply of susceptible tissue for infection, colonization, conidiation, and resulted in a steady increase of scab. Of course, associated with this would be increased difficulty in controlling the disease.

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EFFECT OF NUT SCAB ON PECAN YIELD AND QUALITY COMPONENTS

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ABSTRACT

A test was conducted over a three year period on three pecan cultivars to determine the effect of scab disease on some yield and quality components of pecan production. Disease progress curves were generated and compared for effect on yield and quality values. The effect of scab on yield components ranged from complete crop destruction to reductions in yield weights of five to sixty percent. The major damage caused by scab in this test was recorded from disease increases in Jul. Increases throughout Aug also significantly reduced yield. Extreme scab severity by the end of Jul decreased the oil content of the kernels.

INTRODUCTION

Since its recognition in the late 1800's (Ellis and Everhart 1888), pecan scab has generally been considered to be the most important disease of pecan (*Carya illinoinensis)* in terms of potential crop loss, and economics of control. This disease, incited by *Cladosporium caryigenum* is one of the limiting factors in commercial production of pecans in the southeastern U.S. (Littrell and Bertrand 1981). The statement that scab disease is one of the most economically important factors of pecan production has been made in one form or another in dozens of publications since commercial production began in the early part of this century. Commercial production of pecan cultivars in the southeastern U.S. is dependent on control of scab with multiple fungicide applications each year (Littrell and Bertrand 1981). With the recognition that scab is a serious disease, it could be assumed that the specific effects of the disease on crop production have been extensively studied. However, this is not the situation, in fact, very few research efforts have addressed the effect of the disease on nut production. Previous reports have indicated that leaf damage can vary from defoliation to destruction of localized areas (Demaree 1924, Demaree and Cole 1929). Because of the complexity of directly connecting leaf infections with crop damage in a perennial tree crop such as pecan, there have been no specific data collected to indicate the effect of leaf infection by the scab pathogen on crop development. However, physiological studies, as well as defoliation experiments show that leaf loss does effect production potential of nut trees (Marquard 1987, Sitton 1931, Sparks and Brack 1972, Sparks and Davis 1974, Worley 1971). Most of the reports on scab damage have described total crop loss as a result of extreme nut infection. Many of these reports were based on data obtained during fungicide trials (Demaree 1924, Barnes 1959, Barnes 1966, Barnes 1974, Barnes 1977, Cole 1948, Cole 1964). Generally, scab disease control recommendations had been based on the potential for complete crop loss, and reports that tissue can be infected from bud break through nut maturity.

Two research efforts have specifically addressed the effects of nut infection on yield and quality (Gottwald and Bertrand 1983, Hunter 1983). One report indicated that increases in scab from mid- Jun to nut maturity may not have a significant effect on yield and quality of the crop, and that scab did not cause any increases in total end of year nut drop (Gottwald and Bertrand 1983). The report by Hunter indicated that a direct correlation existed between increase in scab in Jul and late season nut drop (Hunter 1983). As the authors indicated these were preliminary studies into an area that had not been previously investigated.

Because of the importance of this area of research to pecan production practices, a study was initiated in 1991 to collect additional data on the effects of scab on yield and quality components.

PROCEDURES

The test was conducted over a three year period, 1991-1992 at the LSU Agricultural Center Pecan Research-Extension Station. During 1991 and 1993, three cultivars (cv. 'Desirable', 'Schley', and 'Maramec') were included in the study; in 1992 only the 'Desirable' trees had enough nuts to be used. Treatments consisted of disease progress curves which were generated by plotting disease severity with time. Different levels of disease severity were obtained by the use of differential fungicide application schedules to allow for different time periods during the course of the growing season when the nuts were not protected from infection. Each tree was a replicate with individual nut clusters tagged on each replicate. Fungicide applications were applied only to the tagged clusters on each tree throughout the growing season. The clusters were monitored for nut drop and disease severity through the growing season. Disease severity was based on percent of the shuck surface of each cluster that was covered with scab lesions. The severity scale used was: 0%, 1-10%, 11-30%, 31-50%, 51-70%, 71-90%, and 91-100% of the shuck surface covered with lesions. A mean disease severity for each replicate was obtained from the severities of the tagged clusters on each tree. The severity rating for each replicate was used to obtain a mean severity level for each evaluation date for the treatments.

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The nuts in the tagged clusters were collected at shuck split, and allowed to dry at room temperature. After the weight of the nuts had stabilized, the length, diameter, nut weight, and kernel weight of each nut was measured. The calculated means of each replicate were used to compare the effect of the disease progress curves on nut development. The effect of scab on the color of the kernels was determined subjectively by the independent evaluation of four or more individuals who were not familiar with the treatments of the test. The kernels were rated as either golden, light brown, medium brown, or dark brown. The kernels were then sent to the Louisiana State University Agricultural Center Agricultural Chemistry Lab at Baton Rouge to determine the protein and oil percentages.

RESULTS AND DISCUSSION

Representative disease progress curves generated for each cultivar in 1991, along with the corresponding yield component data calculated from the nuts of the tagged clusters are shown in Figures 1-3. Because of frequent rain periods and high rainfall amounts from Apr through Jul, scab development on unprotected nut clusters was intense from late Jun through Jul. This essentially represented a worse case scenario. On the unprotected nuts of each cultivar (Figures 1-3, curve “G”), 85-100% of the nuts in the tagged clusters were aborted by the end of Sep. The disease curves associated with these nut drop totals each had a severity level of 31-50% in the first week of Jul, and were at or near 100% infection by 1 Aug. Interestingly, other disease curves in 1991 were generally not associated with a significant increase in nut drop. For example, on 'Desirable', another curve (not shown) that approached 100% infection in early Aug, and was at a level of 1-10% in early July did not induce excessive nut drop. A 'Maramec' disease progress curve that was at 11-30% in early Jul and reached 100% by mid-Aug (not shown) also was not associated with extra nut drop; however, in other years this type of curve did result in almost complete nut loss.

The 1992 and 1993 growing seasons were closer to “typical” years with regard to scab disease development. The untreated nut clusters of 'Desirable' had infection levels of 11-30% during the first week of Jul, and reached 91-100% in mid- Aug (Figures 4 and 5, curve “F”). Even though this was a considerably slower rate of disease progress than was recorded in 1991, the crop on these trees again suffered high levels of nut drop. The nuts on these clusters had a total drop of 82% and 90% in 1992 and 1993, respectively (Figures 4 and 5). The untreated clusters of 'Maramec' in 1993 (Figure 7, curve “D”) reached the 11-30% infection average near mid-Jul, and 100% after Sep. These nuts exhibited an end of year drop of 43% compared to 25% from clusters associated with final infection levels of less than 11-30% (Figure 7). The untreated 'Schley' nuts in 1993 did not reach 11-30% until near the end of Jul, and this level of disease progress apparently did not induce any additional nut drop. Most of the nut drop associated with scab occurred after the “normal” post pollination drop in Jun, and was most evident in Jul and Aug, although scab induced nut drop continued until harvest (Figure 8).

These observations support Hunter’s conclusion that scab disease can cause late season nut abortion, but no linear correlation was evident between the amount of scab in early Aug and the degree of nut drop induced (Hunter 1983), Generally, an infection level of 11-30% in early Jul, followed by rapid progress in infection so that a level of near 100% infection was obtained by mid-Aug, resulted in nearly 100% end of season nut drop. Other disease progress curves apparently caused a little or no additional nut drop. In 1991, on each of the three cultivars, a progress curve was generated that was 11-30% or higher in the first week of Jul, but had slowed progress through the rest of the season. No additional nut drop was associated with any of these curves (Figures 1 “C”, 2 “D”, and 3 “D”). This suggests that for scab to induce nut drop above the “normal” drop the infection level has to not only be high in early Jul but must continue to progress rapidly to near 100% infection of the shucks.

In 1991, the tagged clusters with the most rapid disease progress curve lost practically all of their nuts (Figures 1-3). A few untagged untreated nuts with severe levels of scab that did remain on the trees until maturity were collected to measure the effect of severe scab on nut size and weight. These nuts were of such poor quality that they would not have been marketable; all three cultivars had a 60% or greater weight loss compared to nuts from clusters with the lowest disease curves. The nuts per pound were 146, 168, and 175 for 'Desirable', 'Schley', and 'Maramec', respectively (Figures 1-3, curve G). Similar results were recorded in 1992 and 1993 with the 'Desirable' nuts collected from the clusters with the most intense disease curves (Figures 4 and 5, curve “F”). There is no doubt that severe infection by early Jul combined with continued disease progress near 100% infection by mid-Aug will destroy a pecan crop through nut abortion and greatly reduced size and weight of those nuts that do reach maturity.

When scab was at a level of 1-10% or lower in the first week of Jul, and increased steadily afterwards through the remainder of the season (Figures 1 “E” & “F”, 2 “F”, 6 “E”, and 7 “D”), loss of nut weight was usually quite large (33 to 47% in the examples), and was influenced by the rate of disease increase. These nuts were also significantly smaller in size and kernel weight. The percent weight loss for these kernels was greater than the percent weight loss of the nuts from these samples and ranged from 38 to 57%. This seems to suggest that scab had a greater effect on kernel development than on shell development. The percent kernel reduction for the examples shown varied form 2 to 12%.

Three curves are shown in which scab is near 1- 10% severity in mid-Jul and increases afterward. The size and nut and kernel weights of the nuts collected from the clusters with two of these progress curves (Figure 4 "D" and "E") were significantly less than nuts collected from clusters with a final disease level of 1-10% in Oct. These two nearly parallel curves illustrate the importance of the rate of disease increase on yield components. The nuts from the clusters that had attained an infection of 60-80% in mid-Aug had a 40% reduction in yield, while those nuts that reached 60 - 80% infection in Oct had a 10 % nut yield loss. The nuts from this later group actually did not exceed 1-10% infection until the end of Jul. The percent kernel weight loss was 45 and 12 for the nuts with corresponding 40% and 10% nut weight loss, while the reduction in percent kernel was 4.1 and 0.8, respectively. Percent kernel is not as useful for evaluating the effect of scab on nut development as is weight of the nuts and kernels, because the primary effect of scab is size and weight reduction while the effect on percent filling is not as pronounced. The nuts collected from the tagged clusters with one of the disease curves in this group (Figure 2 "E") were not reduced in size or weight. Oddly, nuts that were associated with another curve in 1991 on 'Schley' that also was 1- 10% severity in mid-Jul but that increased at a slower rate, were reduced in weight.

Four curves are shown that demonstrate the effect of scab on yield components when the severity level exceeded 1-10% after late Jul or early Aug. The results from the 1992 'Desirable' group curve (10% nut wt and 12% kernel wt. loss) have already been discussed. The other three curves are from 'Maramec' 1991, 1993 and 'Desirable' 1993 (Figures 3 "F", 5 "E", and 7 "C"). These progress curves are similar and the nuts collected from the clusters yielded very similar results. The nut weight loss was 19-24%, and kernel weight reduction was 28-31%, with 4-7% lower kernel shellout compared to nuts from the respective lowest disease curve of each year which were near 1-10% severity at the final evaluation period. Even though there was a large difference in the weight of the 'Maramec' nuts and kernels associated with the development of scab after Jul, there was little or no effect on nut size. The 'Desirable' nuts were significantly reduced in size. It should be noted that the 'Desirable' nuts did not much exceed the 1 - 10% class until after mid- Aug. The greater reduction in kernel weight relative to nut weight loss again suggests that scab has more effect on kernel development than shell growth.

Seven curves are illustrated for increases in scab above 1-10% infection after the middle of Aug. The two curves in this group (Figures 3 "E" and 6 "D") with the fastest rate of progression were on trees with the greatest yield reduction values in this group. The yield values for the nuts from the 'Schley' - 1993 curve were reduced as follows: nut weight 16%, kernel weight 23%, and percent kernel 5.7% (Figure 6 "D"). Nuts from the 'Maramec' - 1991 "E" curve similarly had weights reduced by 14 and 18% for the nuts and kernels, respectively (Figure 3 "E"). The diameters of the respective 'Schley' and 'Maramec' nuts were only slightly reduced, and the nut length was not significantly affected.

Two other curves in this group had progressed from a level of 1-10% in mid- Aug to 31-50% severity in mid-Sep (Figures 1 "B" and 2 "C"). The 'Schley' nuts were reduced in weight by 8% and the kernels by 13%. The 'Desirable' nuts from 1991 curve "B" had a significant kernel weight reduction of 9%. The nut weight was not significantly reduced when compared to nuts collected from the trees with the lowest disease curve; although, the lowest disease curve of 'Desirable' - 1991 had a final severity level of 11-30%. The size of the 'Schley' and 'Desirable' nuts from these two curves was not affected.

The other three curves in the group that increased above 1-10% severity after mid-Aug had only minor disease progression and the nuts associated with these curves exhibited only small or no effects in yield values relative to the nuts from the corresponding lowest disease curves (Figures 2 "B", 4 "C", and 5 "C").

Two curves from 'Maramec' 1991 increased from 1-10% at the end of Aug to 11-30% in mid-Sep (Figure 3 "B" and "C"). Nuts collected from the "C" curve terminals had lower nut and kernel weights, the nuts with the "B" curve severity were not significantly different from the nuts with a final severity of 1-10%, curve "A". The "C" curve had a somewhat higher severity level than the "A" curve from Jul to mid-Aug, and "B" had a lower severity than "A" through mid-Aug. This suggests that even low levels of infection during this period can sometimes reduce yield values.

Two other curves that progressed slowly from 1- 10% at the end of Aug to final severity of near 11- 30% in Oct were the "B" and "D" curves of 'Desirable' - 1993 (Figure 5 "B" and "D"). The yield values were only slightly different than the nuts from the terminals with the lowest disease progress curve, and, in fact, the nuts from the "B" curve were a little larger and heavier than the "A" curve nuts. Unfortunately, no curves were generated that had low levels of scab at the end of Aug with a subsequent rapid disease progression. This was because of a lack of rainfall periods to induce infections, and perhaps because of the decreasing susceptibility of the shucks to infection in Sep. Thus, the potential effects of large increases in scab during Sep were not determined in this test. Results of relatively small differences in scab progression in Sep were not definitive.

It may seem odd for a substantial kernel weight reduction not to be accompanied by a similar amount of reduction in percent kernel, especially in instances where there is no significant change in nut size. One possible explanation of this is that there is a reduction in shell weight even without a detectable change in nut size. To test this possibility, the

five occurrences where a kernel weight reduction was not accompanied by a nut size reduction in this study were examined to see if there was a change in shell weights. The five occurrences were 'Schley'- 1991, “C”, 'Maramec' - 1991 “C” and “F”, 'Desirable' - 1992' “C”, and 'Maramec' - 1993 “C”. In each instance the change in percent kernel could be accounted for by the shell weight and kernel weight changes. Even though these shell weight reductions were small (0.2 to 0.3 g) they represented a 4 to 7.5% weight reduction of the shell. This weight reduction explained the difference between percent kernel weight loss and percent kernel. For example 'Maramec' - 1993 curve “C” (Figure 7 “C”) had a kernel weight reduction of near 28% compared to the kernels from the respective “A” curve, but only a 6.1% decrease in percent kernel. However, the shells of the nuts from the “C” curve also weight 7.3% less than the shells from the “A” group. The shell weight change somewhat negates the effect of reduced kernel weight on percent filling.

Because of the consistency of a reduction in yield components associated with increases in scab severity in Jul and Aug, it would appear to be a good production practice to protect pecans from infection through Aug to prevent economic yield losses. Often growers have the impression that scab has not damaged their crop because the nuts are well filled with normal appearing kernels. A 10% or more reduction in weight may not be easily detected by observation, but it is certainly detectable in terms of profitability. In most production and market situations an increase in yield of 5% would justify the cost of a single fungicide application.

A frequently asked question from growers is if it is economically wise to continue a fungicide application program after a significant level of infection has occurred early in the season. In 1991, an attempt was made to collect data relative to this situation by generating disease curves with relatively high infection levels in Jul followed by a slowed rate of disease progression through fungicide applications. These curves are shown in Figures 1 “C”, 2 “D”, and 3 “D”. As would be expected, the effects on yield components was dramatic. The 'Desirable' curve (Figure 1 “C”) was near a level of 31-50% severity through mid- Aug then progressed to a level of 51-70 % in Sep. The yield values from the nuts with this progress curve were similar to nuts that had a relatively low amount of infection in early Jul and then increased rapidly to over 80% severity at the end of Aug (Figure 1 “F”), yield weights were reduced by almost 40%. Very similar values were recorded for the nuts from the 'Schley' curve that progressed form 11-30% on 3 Jul to 31-50% in early Aug where the severity remained through the end of Sep. Yield weights were reduced by over 40%, and were comparable to nuts collected from the “F” curve which increased in severity from Jul through Sep (Figure 2 “D” and “F”). The 'Maramec' curve in this group had a severity rating of 11-30% in early Jul, but did not reach the 31- 50% level until mid-Sep. The nuts were reduced in weight by over 25% (Figure 3 “D”). These results demonstrate that infection levels of 11-30% in the first week of Jul will cause a major reduction in yield even when scab progression is suppressed through the rest of the growing season. Nonetheless, it is certainly better to harvest 60% of a crop at some market value than to lose the entire crop, which would generally happen if disease was allowed to progress uninhibited throughout the year on susceptible cultivars. The similarity in yield losses between nuts from curves that were relatively high in severity in early Jul with slowed progression through the rest of the year, and nuts from curves that were relatively low in early Jul followed by disease progression through the rest of the season suggests that it is equally important to protect nuts from scab disease throughout most of the season.

The effects of scab disease on quality components were measured as changes in kernel color, and percent oil and protein in the kernels. The effects on quality components were not as dramatic as effects on yield components. Only three of the disease progress curves shown from the test in 1991 and 1992 were associated with kernels that had significantly lower percent oil compared to the curves with the lowest disease severity (“A” curves) (Table 1). These three curves were the ones with the fastest rate of disease development on 'Desirable' in 1991 and 1992, and 'Maramec' in 1991. None of the disease progress curves on 'Schley' in 1991 were associated with an effect on percent oil. These results are similar to previously reported effects of scab on kernel oil content (Gottwald and Bertrand 1983). The flavor of pecans is largely determined by their oil content, there is a possibility that a decrease in percent oil would effect the flavor of the kernels. As the percent oil of the kernels decreases the percent protein tends to increase. It is speculated that the percent of protein increases simply because of the decrease in amount of oil in the kernels.

No consistent effects of scab on kernel color were noted. The kernels from the nuts with the most severe scab were easily recognized because of small size, and sometimes deformed appearance, but even these were apparently not consistently changed in color.

It should be pointed out that determination of the severity of scab was subjective, and was no doubt influenced by the evaluator. It would be useful in evaluating the effects of scab on nut production if a more accurate means of severity determination was available. During severity evaluation no distinction was made between new infections and lesion enlargement from previous infections. This could be particularly important in evaluating late season disease increase.

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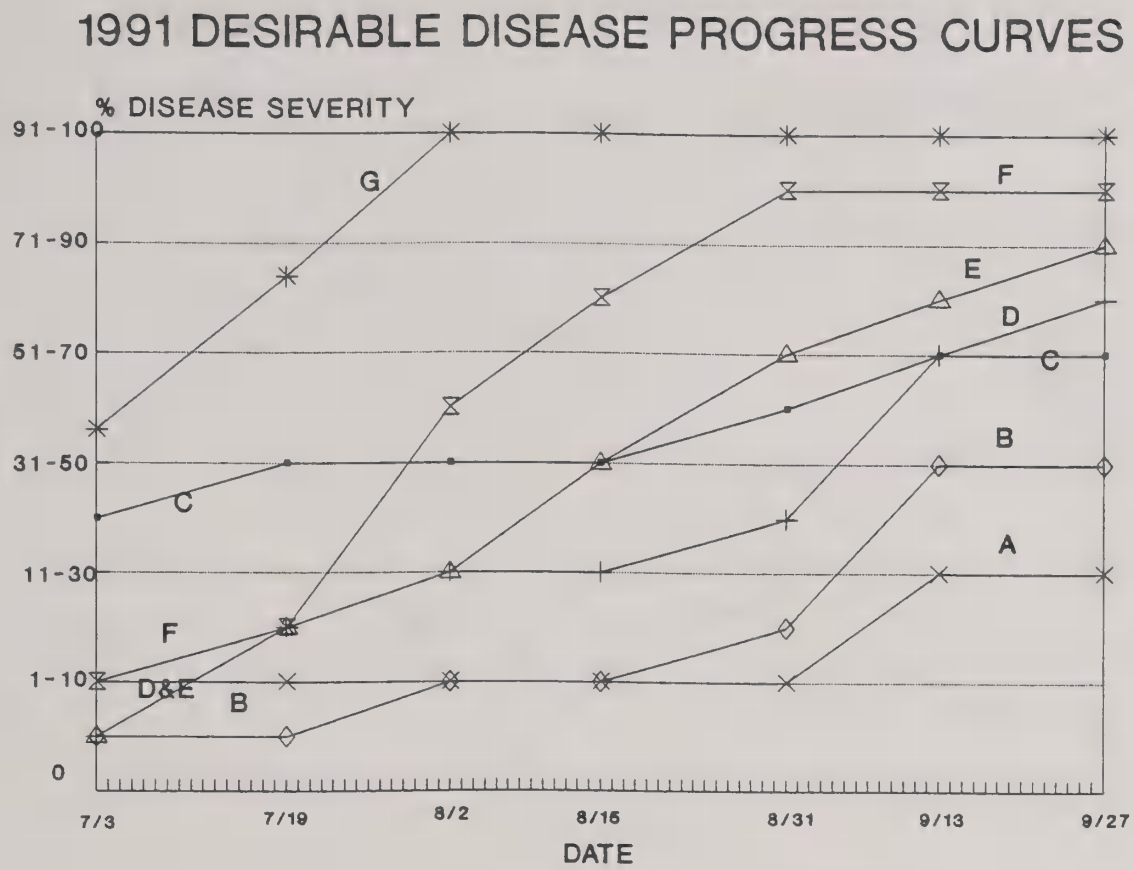
Table 1. Percent of protein and oil in kernels of nuts with various scab disease progress curves.

			Disease Progress Curves[1]													
			A[2]		B		C		D		E		F		G	
			%	%	%	%	%	%	%	%	%	%	%	%	%	%
Fig	Cultivar	Year	Pro	Oil	Pro	Oil	Pro	Oil	Pro	Oil	Pro	Oil	Pro	Oil	Pro	Oil
1	Desirable	91	11.6	58.8	12.5	61.8	12.1	59.7	12.0	57.9	13.7	61.2	13.6	56.8	14.2	44.1*
2	Schley	91	7.9	70.8	7.7	69.7	8.1	71.9	10.3*	67.6	8.7	69.8	9.1	70.1	11.3*	69.5
3	Maramec	91	9.1	68.3	8.3	68.2	8.7	69.3	8.3	69.0	8.5	67.4	9.3	60.4	10.9*	57.8*
4	Desirable	92	11.1	62.0	11.5	62.0	13.0*	59.9	12.8*	62.0	13.0*	62.7	14.6*	46.0*	-	-

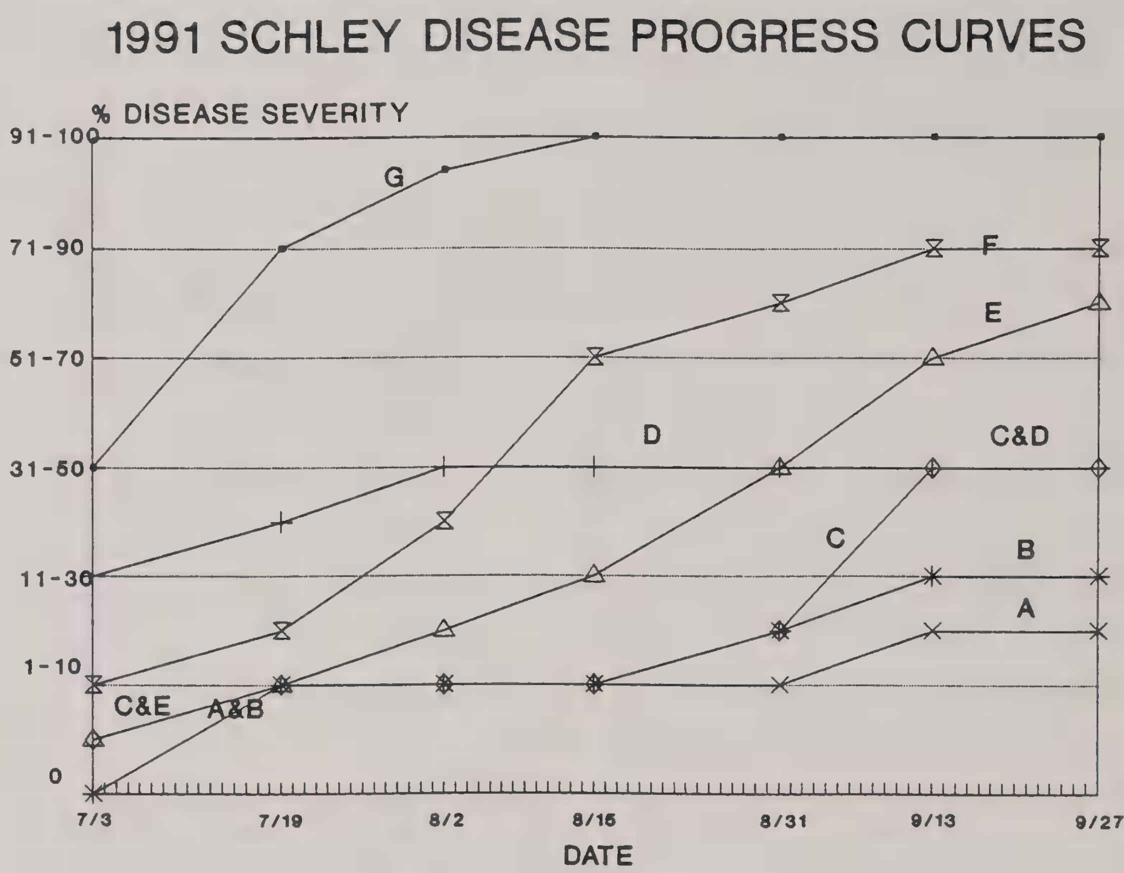
[1] Disease Progress Curve designations from Figures 1-4.
[2] Asterisk indicates significant difference from corresponding value of curve "A" within rows, (LSD, P=0.05).



YIELD COMPONENT VALUES

Curve loss	% Drop	Nut Lgth (mm)	Nut Dia (mm)	Nuts/ lb	Ker/ lb	% Nut wt loss	% Ker wt
A	33	42.4	24.7	48.3	85.6	-	-
B	41	41.8	24.9	49.3	94.5*	-	9.4
C	41	33.5*	24.0	79.6*	141.8*	39.3	39.6
D	30	38.6*	24.5	57.4*	108.0*	15.9	20.7
E	39	36.7*	23.3*	72.0*	137.5*	32.9	37.7
F	38	38.0*	22.0*	79.6*	151.2*	39.3	43.4
G	100	28.9*	19.3*	146.3*	302.4*	67.0	71.7

Figure 1. Representative scab disease progress curves and corresponding yield component values from cv. 'Desirable' in 1991. Asterisk denotes significant difference from "A" curve value (LSD, P=0.05).

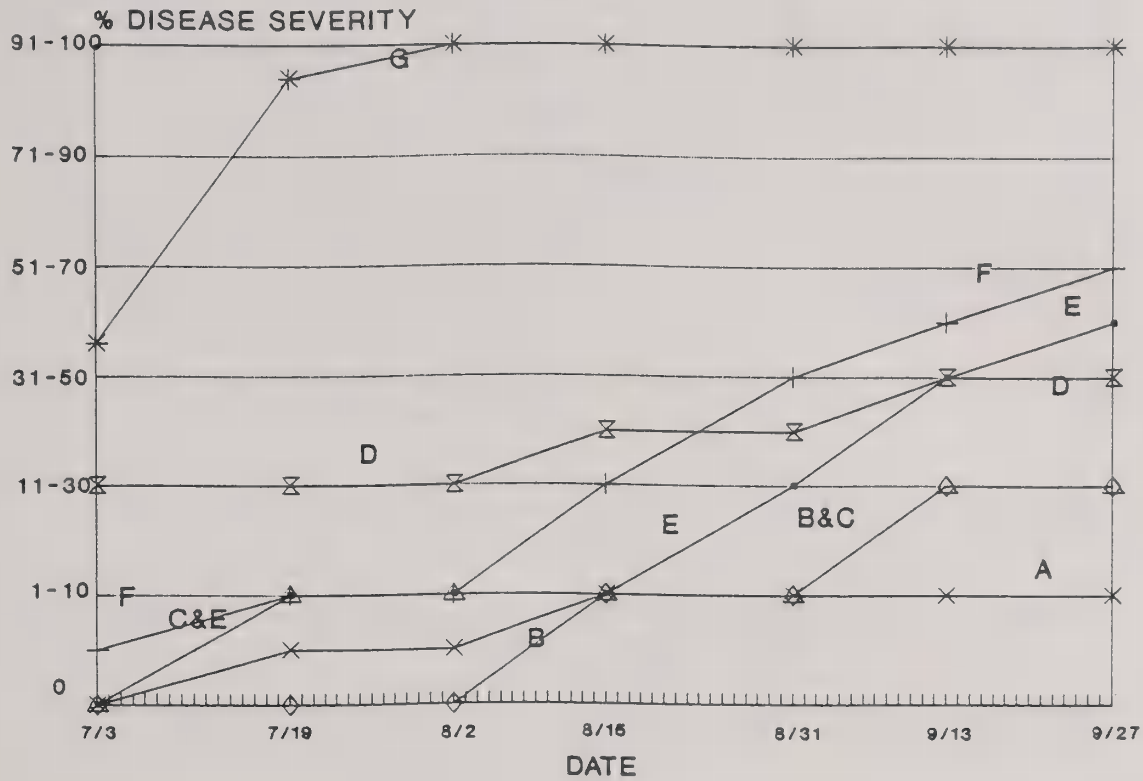


YIELD COMPONENT VALUES

Curve loss	% Drop	Nut Lgth (mm)	Nut Dia (mm)	Nuts/ lb	Ker/ lb	% Nut wt loss	% Ker wt
A	41	44.1	21.1	61.3	98.6	-	-
B	41	44.3	21.4	59.7	96.5	-	-
C	68	44.2	21.2	66.7*	113.4*	8.1	13.1
D	54	37.5*	18.9*	108.0*	181.4*	43.2	45.6
E	58	44.1	21.1	63.0	105.5	-	-
F	73	40.6*	19.5*	103.1*	174.5*	40.5	43.5
G	100	33.6*	15.2*	168.0*	283.5*	63.5	65.2

Figure 2. Representative scab disease progress curves and corresponding yield component values from cv. 'Schley' in 1991. Asterisk denotes significant difference from "A" curve value (LSD, P=0.05).

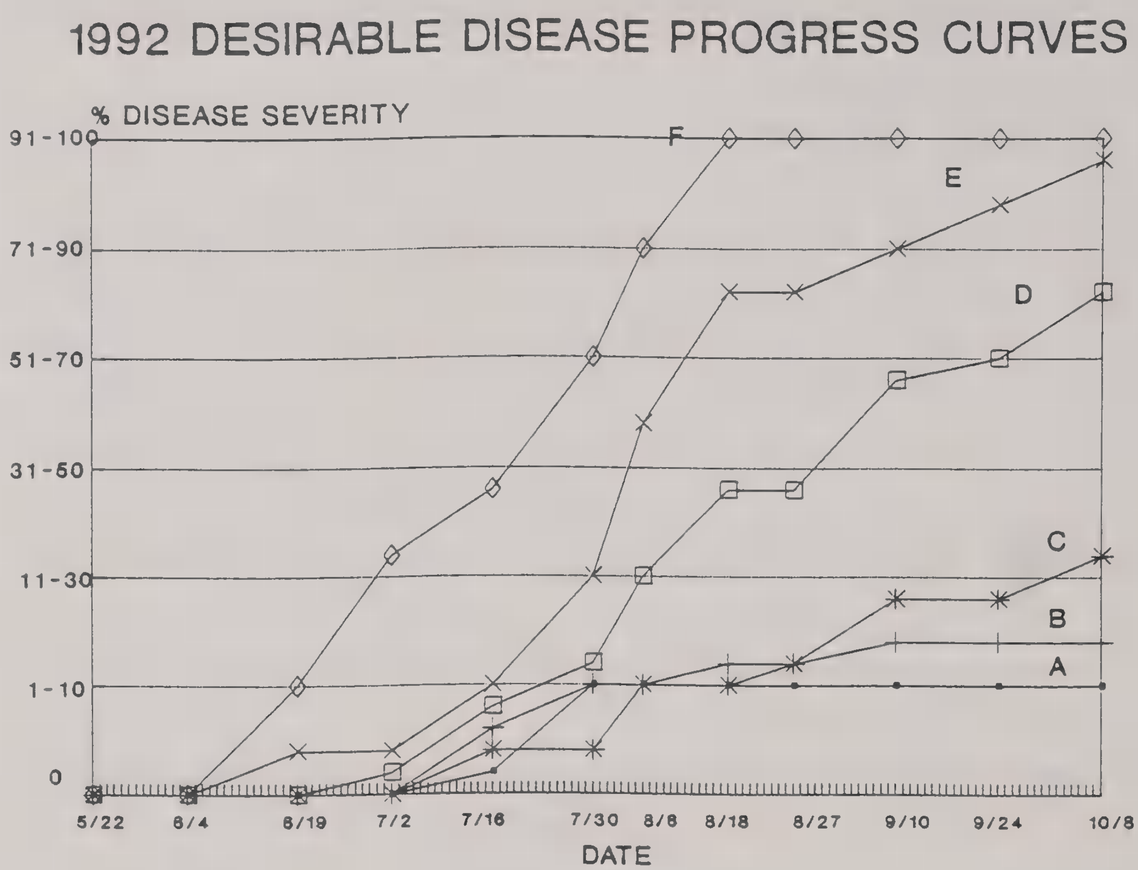
1991 MARAMEC DISEASE PROGRESS CURVES



YIELD COMPONENT VALUES

Curve loss	% Drop	Nut Lgth (mm)	Nut Dia (mm)	Nuts/ lb	Ker/ lb	% Nut wt loss	% Ker wt
A	61	49.5	21.6	46.7	81.0	-	-
B	52	49.9	21.9	47.7	84.0	-	-
C	42	48.9	21.6	51.5*	92.6*	9.3	12.5
D	48	43.3*	20.8*	63.9*	110.6*	26.9	26.8
E	38	48.7	21.2*	54.0*	98.6*	13.5	17.8
F	19	50.0	21.3	58.9*	116.3*	20.7	30.4
G	85	37.1*	17.3*	174.5*	412.4*	73.2	80.4

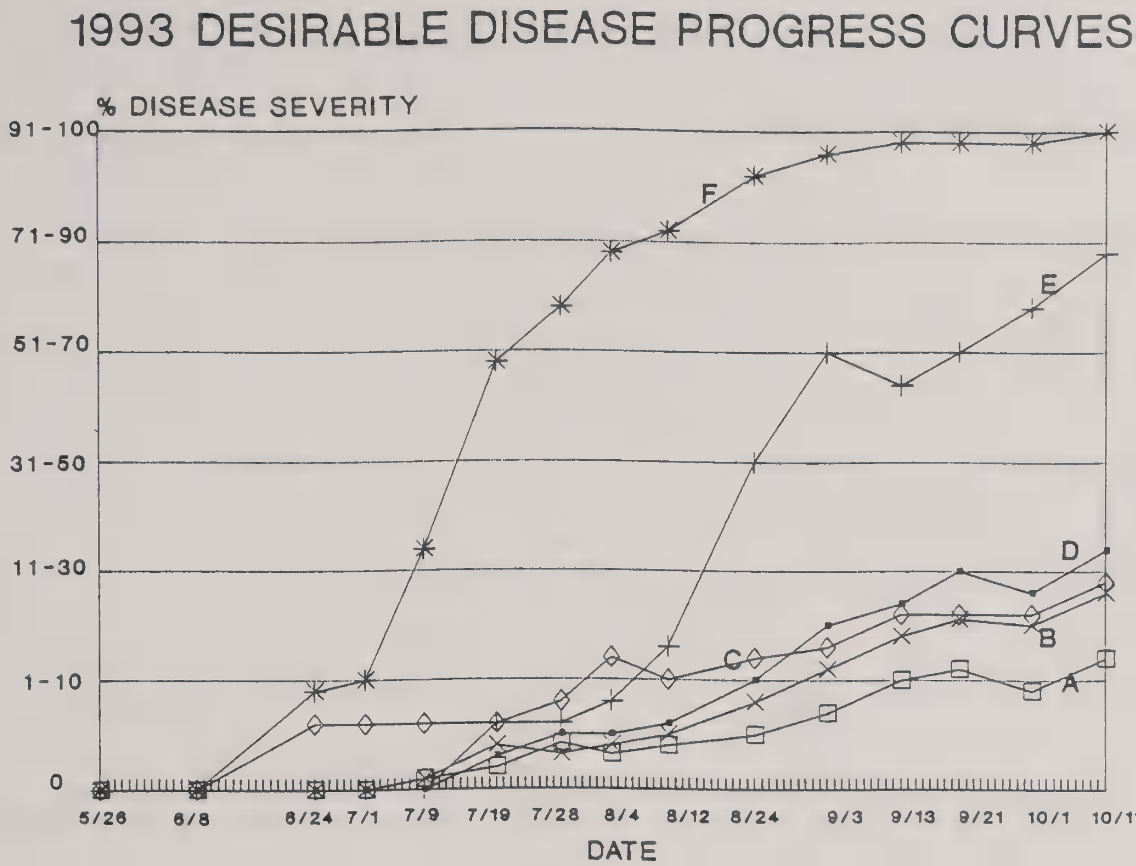
Figure 3. Representative scab disease progress curves and corresponding yield component values from cv. 'Maramec' in 1991. Asterisk denotes significant difference from "A" curve value (LSD, P=0.05).



YIELD COMPONENT VALUES

Curve loss	% Drop	Nut Lgth (mm)	Nut Dia (mm)	Nuts/ lb	Ker/ lb	% Nut wt loss	% Ker wt
A	60	42.6	24.1	49.3	92.6	-	-
B	59	42.8	24.5*	50.4	96.5*	-	4.0
C	59	42.4	24.2	51.5*	96.5*	4.3	4.0
D	58	40.8*	24.1	55.3*	105.5*	10.8	12.2
E	68	37.4*	21.7*	82.5*	168.0*	40.2	44.9
F	82	31.0*	18.7*	162.0*	412.4*	69.6	77.5

Figure 4. Representative scab disease progress curves and corresponding yield component values from cv. 'Desirable' in 1992. Asterisk denotes significant difference from "A" curve value (LSD, P=0.05).

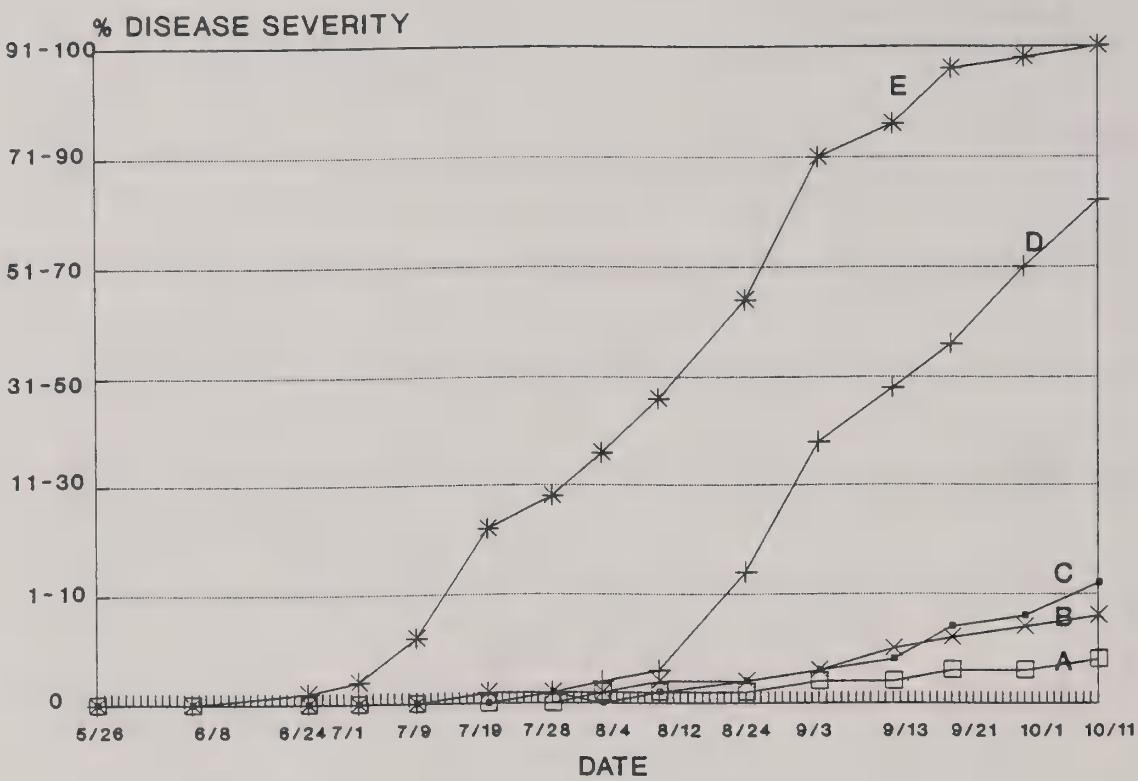


YIELD COMPONENT VALUES

Curve loss	% Drop	Nut Lgth (mm)	Nut Dia (mm)	Nuts/ lb	Ker/ lb	% Nut wt loss	% Ker wt
A	39	42.9	23.7	49.8	98.6	-	-
B	43	43.6*	24.1*	48.3*	92.6*	-	-
C	52	42.0*	23.6	52.1*	103.1*	4.4	4.4
D	48	43.5*	24.1*	50.4	100.8*	-	-
E	43	41.2*	22.8*	65.7*	141.8*	24.2	30.5
F	90	32.9*	19.8*	126.0*	324.0*	60.5	69.6

Figure 5. Representative scab disease progress curves and corresponding yield component values from cv. 'Desirable' in 1993. Asterisk denotes significant difference from "A" curve value (LSD, P=0.05).

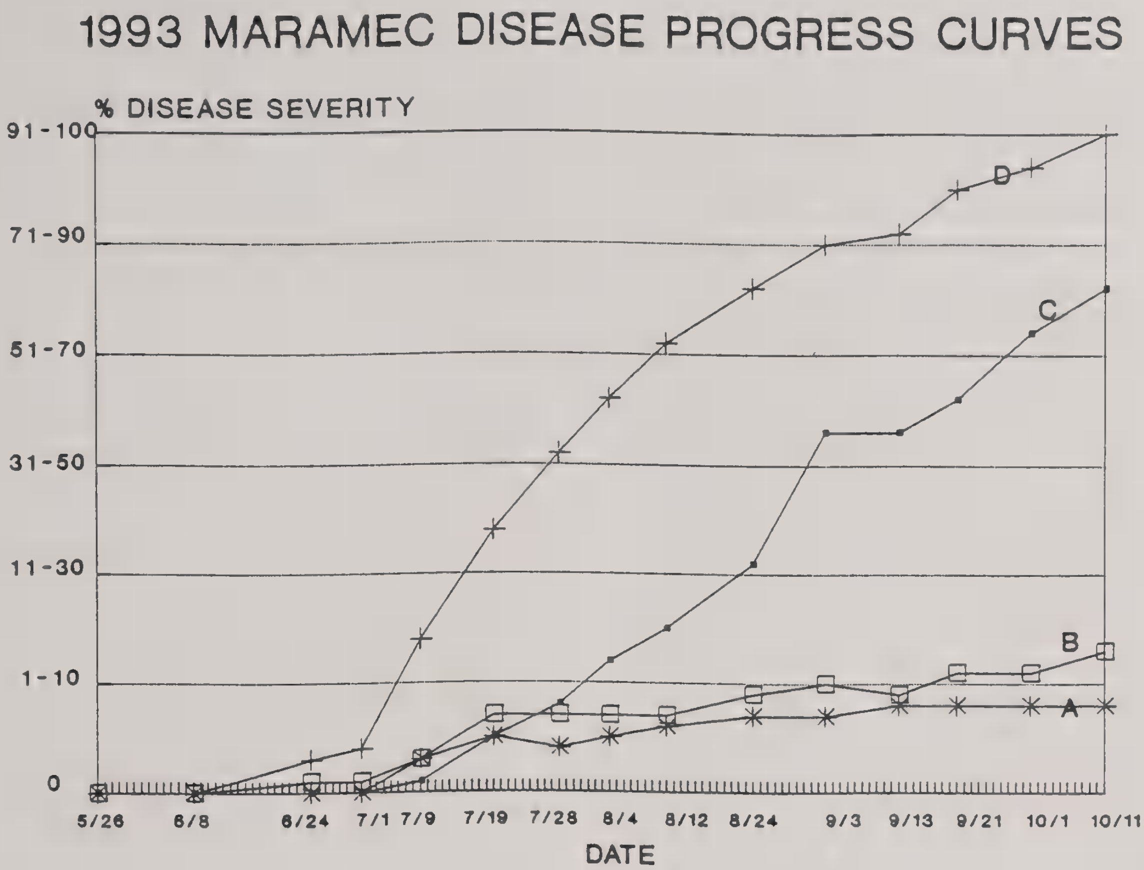
1993 SCHLEY DISEASE PROGRESS CURVES



YIELD COMPONENT VALUES

Curve loss	% Drop	Nut Lgth (mm)	Nut Dia (mm)	Nuts/ lb	Ker/ lb	% Nut wt loss	% Ker wt
A	49	43.6	21.1	58.9	98.6	-	-
B	41	43.9	20.9	58.2	98.6	-	-
C	44.6*	21.1	57.4	98.6	98.6	-	-
D	47	43.6	20.8*	72.0*	133.4*	16.0	22.7
E	55	40.7*	19.5*	113.4*	238.7*	46.6	56.8

Figure 6. Representative scab disease progress curves and corresponding yield component values from cv. 'Schley' in 1993. Asterick denotes significant difference from "A" curve value (LSD, P=0.05)

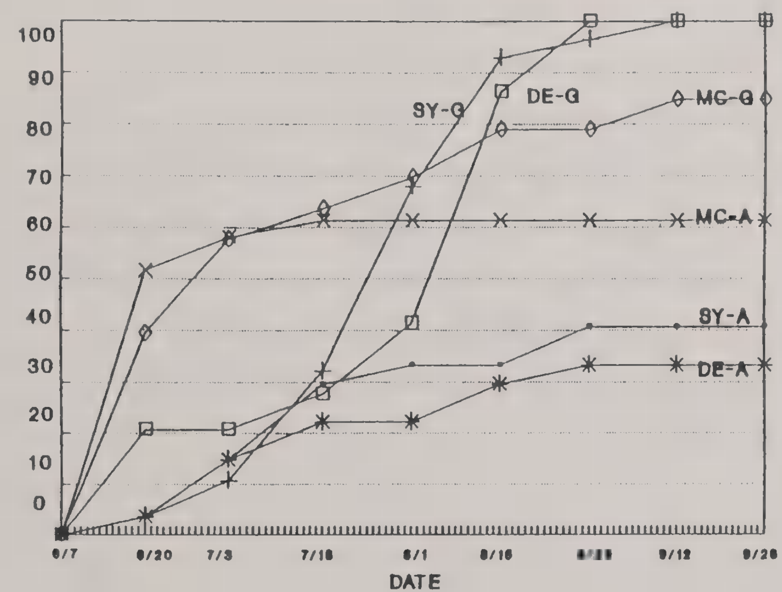


YIELD COMPONENT VALUES

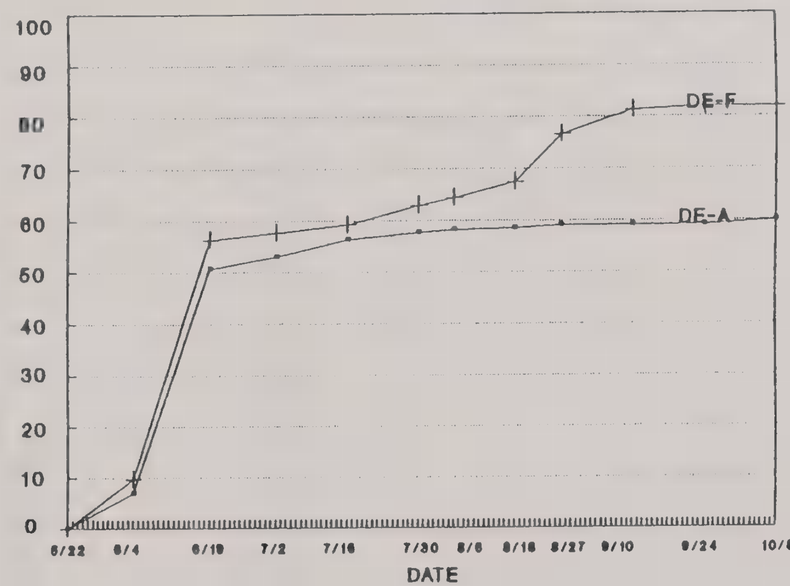
Curve loss	% Drop	Nut Lgth (mm)	Nut Dia (mm)	Nuts/ lb	Ker/ lb	% Nut wt loss	% Ker wt
A	25	49.0	21.6	45.8	78.2	-	-
B	24	48.3*	21.6	47.7*	82.5*	4.0	5.2
C	36	48.5	21.6	56.7*	108.0*	19.2	27.6
D	43	42.9*	19.4*	82.5*	162.0*	44.5	51.7

Figure 7. Representative scab disease progress curves and corresponding yield component values from cv. 'Maramec' in 1993. Asterisk denotes significant difference from "A" curve value (LSD, P=0.05).

1991: cv. Desirable, Schley, Maramec



1992: cv. Desirable



1993: cv. Desirable, Schley, Maramec

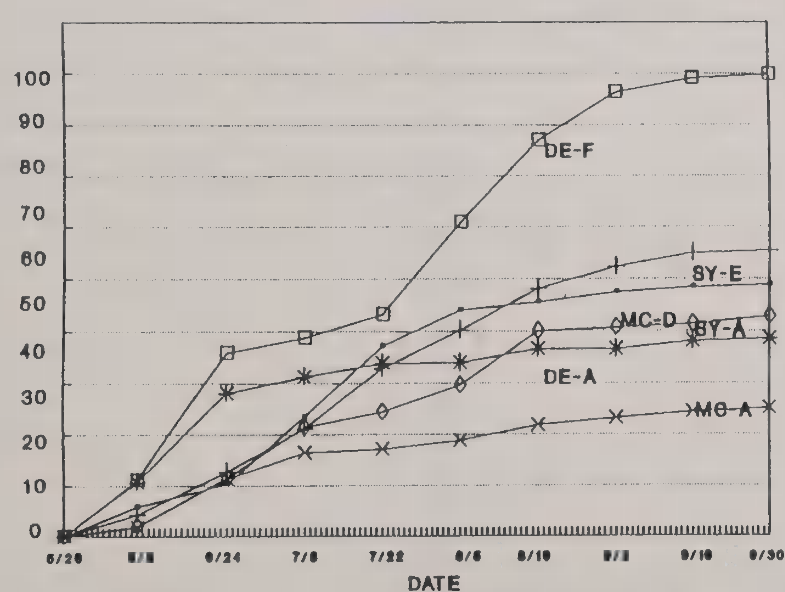


Figure 8. Cumulative percent nut drop patterns associated with the disease progress curves with the least and most disease severity of Figures 1-7. DE=Desirable, SY=Schley, Mc=Maramec.

PECAN SHUCK DISORDERS - A HORTICULTURAL VIEW

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Additional index words. *Carya illinoensis*, shuck disease, fruit thinning, microscopy

ABSTRACT

The influence of fruiting stress on shuck decline and nut quality was evaluated on trees of pecan [*Carya illinoensis* (Wangenh.) C. Koch]. Fruit at the liquid endosperm stage were removed from trees with a mechanical shaker to reduce crop load by 0%, 25%, 41%, 56%, or 77%. Shuck decline decreased and kernel quality increased with a reduction in crop load. An excessive fruit load or fruit stress elevated the incidence of shuck decline, previously referred to as shuck disease, tulip disease, shuck die-back, or late season shuck disorder; and decreased kernel development. Shucks were dissected from fruits ranging from healthy to those with premature shuck opening and examined by scanning and transmission electron microscopy as well as light microscopy. Fungal growth was detectable, but only after tissue degeneration had occurred. Thus, the onset of shuck decline is caused by stress associated with an excessive crop load and not a pathological disorder. Fungal growth is a secondary, not a primary, factor in deterioration of shucks with decline.

Fruit development in pecan is an exhaustive process which imposes stress on the tree (Davis and Sparks 1974, Sitton 1931, Smith et al. 1993, Sparks and Brack 1972). Stress from fruit development is manifested in poor nut quality (incomplete kernel development) often produced by prolific pecan cultivars, especially by mature trees (Sparks 1990). Often poor quality is concomitantly associated with shuck (involucre) deterioration which may result in premature shuck opening in severe cases. This condition has been designated by a variety of terms including shuck dieback, shuck disease, and tulip disease (Halliwell 1968, KenKnight 1968, Payne et al. 1979, Schaller and KenKnight 1972, Schaller et al. 1968), although data were not presented to support a disease (Halliwell 1968, Schaller et al. 1968). Shuck deterioration associated with tree stress was not considered by Schaller et al. (1968) to be an infectious disease or by Halliwell and Johnson (1972) to be caused by a pathogen. Halliwell and Johnson (1972) induced shuck deterioration by ethylene treatment which supports the involvement of tree stress in development of this malady. Contrary to the association of tree stress with shuck deterioration, Reilly and co-workers (Brenneman and Reilly 1989, Hotchkiss et al. 1993, Reilly 1989, 1990, 1992, Reilly and Hotchkiss 1991) recently concluded the causative agent to be the fungus *Glomerella cingulata* (Stoneman) Spauld. and H. Schrenk [anamorph = *Colletotrichum gloeosporioides* (Penz.) Penz. and Sacc. in Penz.].

Shuck deterioration associated with fruit stress is often, but should not be, confused with another shuck disorder which has been termed stem-end blight (Schaller and KenKnight 1972). Stem-end blight is characterized by a gray-brown or black spot which first appears at or near the proximal end of the immature shuck. The spot enlarges and can engulf the entire shuck. The dead shuck may stick to the nut producing a “sticktight”. Stem-end blight occurs earlier in the growth cycle of the fruit (early August in the southeastern United States) than does shuck deterioration from fruiting stress (early to late September). Fungicide sprays reduce the incidence of stem-end blight (Schaller and KenKnight 1972), but have not been shown to reduce the incidence of shucks deteriorating from fruiting stress (Hotchkiss et al. 1993, Latham and Campbell 1991).At least two reasons account for the confusion in the literature on the nature of shucks failing to develop normally. First, symptom descriptions are ambiguous. Second, several abnormal conditions are often grouped into one category, such as shuck disorder. The terminology shuck decline will be used henceforth in this study to designate shuck deterioration associated with tree stress. Shuck decline begins as a thin, dark, necrotic line on the inner surface of the shuck at the junction with the shell. At this stage, the outer surface of the shuck is normal in appearance. Once necrosis begins on the inner surface, it spreads rapidly towards the exterior surface of the shuck. The interior of the shuck turns dark green and slimy and the surface of the shuck appears to be water-soaked exhibiting a green sheen. Later, the entire shuck turns black. If decline begins during early fruit development, the black fruit falls from the tree or opens prematurely and remains in the cluster (Sparks 1992 a,b).

Circumstantial evidence for fruiting stress as the prerequisite for shuck decline has accumulated from extensive observations of crop load by year, tree, cultivar, and shoot vigor. Years of severe shuck decline are concurrently accompanied by high fruit loads; whereas, years with little or no shuck decline are associated with light to moderate fruit loads (Sparks 1992b, 1993). Observations in a mature orchard with variable fruit set among trees,

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likewise, show shuck decline occurs in direct proportion to the degree of fruiting. Also, prolific cultivars, such as 'Success', 'Wichita', 'Cherokee', 'Cape Fear', 'Choctaw', 'GraBohls', and 'Chickasaw', usually produce high quality nuts without shuck decline as young trees; but quality decreases and shuck decline increases in these cultivars as the leaf to fruit ratio decreases with tree maturity. Mature trees of prolific cultivars have good nut quality and a low incidence of shuck decline during the "off" year of production with the reverse occurring during the "on" cycle of the alternate bearing sequence. This alternation of shuck decline has long been observed with 'Success', a prolific cultivar which is classically known for poor quality and a high incidence of shuck decline during the "on" cycle of fruit production (Sparks 1992a). Furthermore, shuck decline on 'Success' trees with similar crop loads decreases as shoot vigor increases (Schaller et al. 1968, Sparks 1992a). An inadequate leaf to fruit ratio (Sitton 1931) from less leaf area on short shoots (Sparks 1966) probably accounts for the increase in shuck decline with decreasing vigor.

Shuck decline is apparently associated with excessive fruiting. The objective of the current study was to determine the effect of fruiting stress on shuck decline.

MATERIALS AND METHODS

The experimental site was near Crystal City, Texas in a 13-year-old, flood-irrigated orchard. The site was selected because 'Wichita', the major cultivar in the orchard, is very susceptible to shuck decline (Sparks 1993). Thirty trees, with crop loads judged to be excessive, were selected for study on 22 July 1993. Previous experience in this orchard had shown that trees with excessive crop loads developed shuck decline and poor kernel quality. Heavy crop load was verified by determining that 99% of the shoots were fruiting and that cluster size of fruiting shoots averaged 4.5 fruit. Calculations based on number of nuts per tree indicated that yield per acre would have been about 5,000 pounds per acre had the trees filled the nuts with well developed kernels. The excessive nut production resulted in severe tree dieback the following spring (Fig. 1). Fruit induced dieback has been reported previously for prolific cultivars (Hunter and Hammar 1948, Sparks, 1994) including 'Wichita' (Sparks 1994).

Fruit were thinned mechanically on 22 and 23 July to remove a projected 0%, 20%, 40%, 60%, or 80% of existing fruit from the selected trees. Actual percentages of fruit removed were calculated at harvest to be 0%, 25%, 41%, 56%, and 77%, respective to the projected percentages. Fruit were thinned during the liquid endosperm stage (water stage) of development. Most fruit were near maximum liquid endosperm stage with a few fruit (about 10%) slightly past this stage. Initial shell hardening was completed on some (about 10%), but not all, fruit. Fruit development stage was within the range recommended for mechanical fruit thinning of pecan (Reid et al. 1993, Smith et al. 1993) which is before the major stress of kernel development (Davis and Sparks 1974). The fruit removed were weighed by tree. A sample of about 225 fruit was taken per tree to determine fruit weight which, in turn, was used to calculate the total number of fruit removed from each tree.

Nuts were harvested by tree on 24 Sept. Before harvest, the number of fruit on each of 100 shoots was recorded by tree. On the same day and also prior to harvest, a random sample of about 100 fruit were collected from each tree to rate shuck decline. Fruit from this sample were then dehulled and weighed. Nuts were air-dried at about 25C. Nut, shell, and kernel weight, percent kernel, and percent edible kernel (U.S. No. 1 grade) were determined individually for nuts. The remainder of nuts were harvested by tree; dehulled; weighed; dried in a pecan wagon by ambient, forced air for 2 days; and weighed again. Prior to drying, a sample of about 125 freshly dehulled nuts were collected by tree and weighed. Fresh weight of dehulled nuts of both samples was used to calculate the number of fruits per tree at the time of harvest. Percentage of fruits removed by mechanical thinning was calculated from number of fruits removed on 22 July and number on the tree at harvest time.

Shuck decline was categorized relative to no decline (Fig. 2A) on the basis of increasing severity into three stages as water-soaked (Fig. 2B), black shuck (Fig. 2C), and black shuck that had opened- prematurely (Fig. 2D). Salmon colored fruiting bodies described as characteristic of *G. cingulata* (Reilly 1989, 1990, Reilly and Hotchkiss 1991) were evident on the shucks of some fruits in the last two stages of decline.

Shucks were dissected from fruits ranging from healthy to premature shuck opening for examination by light microscopy (LM), scanning electron microscopy (SEM), and transmission electron microscopy (TEM). Sections were taken at the midpoint of the fruit perpendicular to the long axis of the fruit and thus, cross sections of the vascular system. Sample preparation was as previously described (Sparks et al. 1994).

The experimental design was a randomized complete block replicated six times with one tree per experimental unit. Results were delineated by regression analysis (Gomez and Gomez 1984).

RESULTS AND DISCUSSION

Healthy pecan shucks had an outer, central, and inner tissue zone, distinguishable on the bases of cell size and shape (Fig. 3A). The outer zone consisted of about four layers of small, rectangular cells whose long axis was parallel to the surface of the fruit (Fig. 3A and B). The central zone composed the major portion of the shuck and began about

0.1 mm from the surface (Fig. 3A to D). Cell size increased and shape became more elongated perpendicular to the shuck surface with each progressive layer toward the interior of the shuck. The third and inner tissue zone of the shuck was made up of about ten layers of small, rounded cells (Fig. 3A, C, and D). Globules of about 50 μm diameter (Fig. 3D) filled some, but not all, inner zone cells and were not observed at all in cells of the other two tissue zones.

An obvious difference, microscopically and macroscopically, between healthy and black shucks (Figs. 3A and 4A, respectively) was the reduced thickness of black shucks. Another difference was in the shuck consistency. Healthy shucks were firm so cuts made with a razor blade were smooth; whereas, shucks with decline were flaccid and not adaptable to sectioning with a razor blade as evidenced by tearing. The outer, central, and inner tissue zone could be identified in shucks blackened from decline (Fig. 4A) as in healthy shucks. However, differences in cell shape among the zones was not as accentuated as in a normal shuck, especially elongation in the central zone (Figs. 4A and B vs. 3A and B). Globules occurred in cells of the inner and central zones of black shucks (Fig. 4C to E); whereas, they were restricted to the inner zone of healthy shucks (Fig. 3C and D). Thus, basic tissue zonation in the pecan shuck was not altered by decline, but cell shape and content were altered in the central tissue zone. Furthermore, differences in tissue consistency indicate that the rigidity of the cells was affected by shuck decline.

Shucks dried and black from the normal process of senescence were examined for similarities and/or differences to shucks in the black stage of decline. Many cells in shucks black from normal senescence had convoluted walls (Fig. 5A) in contrast to the regular shape of cells walls in shucks with decline (Fig. 4C). Some cells in the central zone were filled with globules with a smooth surface (Fig. 5A) characteristic of those observed in shucks with decline. Other cells had structures with a crystalline appearance (Fig. 5B) which were presumed to be calcium oxalate (Gallaher and Jones 1976). However, we propose that the smoother appearing globules are the products of normal shuck senescence. Because globules occur earlier and are more numerous in declining shucks, we further propose that shuck decline is an acceleration and accentuation of the condition occurring with normal senescence.

The progression of decline though the tissue zones was characterized from free hand sections with increasing severity of decline. Light microscopy of these sections (Fig. 6) confirmed SEM observations that rounded cells of the inner tissue zone adjacent to the shell had two different cytoplasmic contents. Healthy shucks (Fig. 6A) without a macroscopically visible blackness had many cells with a dense, reddish brown cytoplasm. Interspersed among the dense cells were layers of cells with a translucent cytoplasm. Once decline became obvious as a thin black line, most inner tissue zone cells appeared occluded with a black deposit (Fig. 6B). As decline progressed to the water-soaked stage, black globules appeared in an occasional elongated cell in the central tissue zone (Fig. 6C). Most of the inner tissue zone appeared as a black, amorphous mass. In black shucks, dark globules were common throughout the central zone with most cells containing one or more of these structures (Fig. 6D). In summary, free hand sections demonstrated the macroscopic black appearance of shucks was due to intracellular dark globules. However, these sections were not satisfactory for defining the stage of shuck decline that might be associated with fungal growth as proposed previously (Brenneman and Reilly 1989, Hotchkiss et al. 1993, Reilly 1989, 1990, 1992, Reilly and Hotchkiss 1991).

An apparent secondary role of microorganisms in the progression of shuck decline was documented in tissue sections made with a microtome and examined with LM and TEM (Fig. 7). Analyses were confined to shuck tissue near the shell in which decline was first manifested, the area at the junction of the inner and central zone. Cells appeared to have a translucent cytoplasm in healthy shucks from free hand sections and was confirmed by microtome sections at the level of LM and TEM to have a sparse cytoplasm (Fig. 7A and B, respectively). Cytoplasm was restricted primarily to the cell periphery and composed of small, dense globules of various dimensions. The middle lamella of adjoining cells and lacunae present at some sites were evident from TEM (Fig. 7B). No evidence of fungi was present at the level of either light or transmission electron microscopy for healthy shucks (Fig. 7A and B, respectively). Shucks with macroscopic evidence of early stages of shuck decline, i.e. a thin black line next to the shell, had cells similar to the normal shucks except for an increase in the size and abundance of globules (Fig. 7C and D, respectively). No evidence of fungal growth was present either inter- or intra- cellularly (Fig. 7D).

Intercellular fungal growth became obvious after deterioration advanced to the water-soaked stage of shuck decline in microtome sections by LM (Fig. 8A) and was confirmed by TEM (Fig. 8B and C). Fungi were observed growing between cells in the region of the middle lamella (Fig. 8B) as well as the lacunae (Fig. 8C).

Free hand shuck sections were treated with histological stains for starch, protein, fat, tannin, and polyphenol in an attempt to determine the chemical nature of the globules. However, no definitive identification was possible based on histological procedures because of the interference of the natural coloration of the globules with evaluation of the uptake of stains.

In summary, anatomical evidence indicated fungi became established only after the plant cells were deteriorating. The major change in the cytoplasmic content of plant cells in the early stages of decline was an abundance of electron dense globules which occurred before fungal growth. No penetration sites of *G. cingulata* on the shuck exterior were found in a concentrated study involving biweekly field inoculations of the fungus onto shucks from mid-June until August (Kerrigan 1993). The same study reported that acervuli of *G. cingulata* emerged through shuck surfaces, sometimes on previously asymptomatic tissues. The current investigation along with that of Kerrigan (1993) indicate that fungal growth which followed shuck decline was initiated in the inner tissue zone of the shuck and progressed to the exterior.

Mid-season fruit removal had a dramatic effect on the incidence of shuck decline. For each stage of decline, decreasing fruit load decreased the percentage of fruit exhibiting shuck decline symptoms (Fig. 9). Kernel quality, measured as percent kernel or as edible kernel, increased with the percentage of fruit thinned (Fig. 10). The data clearly document that shuck decline is due to fruit stress. Our data also show that poor kernel development, concomitantly associated with shuck decline, is likewise due to a fruiting stress. Although a fungus or fungi are present in shucks affected with decline, microbial growth occurs after the onset of decline. Thus, as emphasized by Halliwell and Johnson (1972) and Schaller et al. (1968), shuck decline is not caused by a pathogen. Lack of a pathogen is also supported by the fact that application of conventional pecan fungicides has not been shown to prevent shuck decline (Hotchkiss et al. 1993, Latham and Campbell 1991) and by the inability to induce decline after field inoculations of *G. cingulata* (Kerrigan 1993).

Fruit thinned from 25% to 41% maximized nuts; 41% fruit thinning maximized kernels; and maximum edible kernel occurred at 56% to 77% thinning (Fig. 11). The key parameter is edible kernel which represents marketable yield. Maximum marketable yield occurred with 56% fruit thinning. This thinning level corresponded to 72% of the shoots retaining fruit with an average cluster size of 2.9 fruits on fruiting shoots. Although shuck decline (Fig. 9) was minimal at the highest level of fruit thinning, decline was still present suggesting a stress factor in addition to fruiting. Insufficient soil moisture was indicated by occasional dead and non-abscised leaves, a symptom of moisture stress.

Although fruiting stress is a prerequisite for shuck decline, high fruit load does not result necessarily in shuck decline. Instead, data and many observations indicate that shuck decline most commonly occurs when fruit stress is accentuated by other factors. Inadequate sunlight and soil moisture stress are apparently two major accentuating factors for shuck decline. Shuck decline on 'Success' and other cultivars can be more pronounced on the shady than the sunny side of the tree, as on border rows. Similarly, decline has been observed to be worse in crowded than open areas of an orchard (Schaller et al. 1968, Sparks 1992a). Excessive shade, as suggested by repeated observations, appears to be a major factor in the induction of shuck decline even on cultivars that are not prolific, for example, 'Desirable'.

Soil moisture stress was associated with acute shuck decline in the southeastern United States in 1991, a year of excessive fruit load (Sparks 1992b). Record-breaking rainfall occurred during most of the growing season until about mid-August. Water-logging, which Schaller et al. (1968) also observed to be associated with shuck decline, occurred frequently. Stress was further accentuated by a record-breaking drought from mid-August to mid-September. During the drought, massive premature defoliation occurred in non-irrigated orchards. Premature defoliation under conditions of a high fruit set, as in this case, is especially stressful (Sparks and Brack 1972). Additionally, poor nut quality could be expected under soil moisture stress as kernel development is critically dependent on adequate soil moisture (Sparks 1992 a,b). Pecans had massive shuck decline in southern Brazil in 1993, a year with weather patterns similar to the southeastern United States in 1991 when rains were excessive during most of the growing season followed by a drought during kernel development (Geraldo T. Linck, personal communication). Also, as in the southeastern United States, shuck decline was severe on the prolific cultivars, 'Wichita', 'Barton', 'Shoshoni', and 'Cape Fear', but was only minor on the non-prolific 'Desirable'.

In 1991, shuck decline in Georgia was less severe in orchards with adequate irrigation during the drought than in orchards with no or inadequate irrigation. The role of soil moisture was strikingly illustrated in orchard blocks where inadequate irrigation resulted in massive shuck decline caused by water stress. In the same orchard, shuck decline was not a problem in blocks with adequate irrigation (Sparks 1992b). Yields of pecans in Georgia, in 1992, were below normal with favorable soil moisture resulting in few problems of shuck decline or nut quality. In 1993, a drought year, pecan yields were above normal. Good nut quality with minimal, if any, shuck decline occurred in orchards which had adequate irrigation or timely rains during kernel development. However, orchards with insufficient soil moisture from lack of either rain or adequate irrigation during kernel development sustained damage from shuck decline and poor quality nuts.

An extreme case of water-logging occurred in an orchard with heavy fruit set in southwest Texas during 1990 (Sparks 1993). Water-logged conditions, which are detrimental to pecan (Smith and Ager 1988, Smith and Bourne 1989), were created by excessive irrigation during most of the growing

season followed by excessive rains (229 mm) during kernel development. Shuck decline was obvious long before fruit maturity occurred resulting in reduced kernel quality. Pecan yields for 1991 were light, with good nut quality and little, if any, shuck decline. Yields were high in 1992, but in contrast to 1990, soil moisture conditions were more favorable for healthy fruit development. Shuck decline was not observed until near shuck dehiscence and with no detectable effects on kernel quality. Other workers (Schaller et al. 1968) also observed variable effects of shuck decline on kernel quality depending on the developmental stage of the kernel at the time of stress. Stress imposed at the middle of kernel development was detrimental to kernel quality, but late season stresses imposed near fruit maturity had little, if any, effect on quality.

The accentuation of fruiting stress by other accompanying stress factors, i.e., drought, premature defoliation, water-logged soils, shady conditions, etc. will make it difficult to establish an absolute threshold of fruiting intensity at which shuck decline will not occur. Observations indicate that shuck decline normally is not a problem if stress factors other than fruiting are not in effect in non-prolific 'Desirable', 'Schley', and 'Stuart', the major cultivars in the southeastern United States. However, with prolific cultivars, such as 'Wichita', selective fruit thinning is apparently essential to prevent shuck decline induced by excessive fruiting as such.

In summary, decreasing tree stress by mechanical fruit thinning had a direct impact on fruit maturation by decreasing shuck decline and increasing kernel quality. Thus, shuck decline, previously referred to as shuck disease, tulip disease, shuck die-back, or late season shuck disorders is due to an excessive fruit load as is poor kernel development associated with shuck decline. Onset of shuck decline should be treated as a problem of tree physiology and not a pathological problem as fungal growth was not detectable microscopically until cellular breakdown was evident. The data presented in this paper provide insight into the management of a problem which has resulted in multi-million dollar losses in the pecan industry.

RECOMMENDATIONS

1. Fungicide should not be applied in an attempt to control shuck decline. The disorder is not a disease. Instead, measures should be taken to reduce tree stress.

2. Cultivars that are prolific, like 'Wichita', will require mechanical fruit thinning during heavy "on" years of the alternate bearing cycle. Otherwise, poor quality will result. Relatively non-prolific cultivars, for example, 'Stuart', 'Schley', and 'Desirable' will not, as a general rule, require mechanical fruit thinning in most years.

3. Keep the orchard open by removing trees before mutual tree shading becomes a major problem. As a general rule, an orchard is too crowded if the sod within the row middles has been shaded out. Tree thinning should begin just as the sod begins to shade out.

4. Irrigate and especially during the 4 to 5 week period before shuck dehiscence which is the interval of major kernel growth. Inadequate soil moisture during the kernel development period is the number one factor inducing shuck decline in the southeastern United States. A minimum of 1.25 inches of water per acre per week are needed during this interval. Most drip systems were not designed to deliver this volume of water.

5. Unless a prolonged drought occurs, gradually increase drip irrigation as follows. Run the systems 4 hours per day in May, 6 hours per day in June, 8 hours per day from July until mid-August, and 12 hours per day from mid- August until frost. Scheduling irrigation in this manner will minimize nut size. A smaller nut requires less energy for kernel filling than a larger nut, thus minimizing the stress of fruiting.

6. In pecan breeding and selection programs, special attention must be paid to prolificness. Highly prolific cultivars should be released only with the understanding that fruit thinning will be required. Even then mechanical fruit thinning may be only partiall successfully as some cultivars have a tree structure that is not conducive to efficient fruit thinning. Cultivars with an upright tree structure can mechanically thinned more successfully than those with a spreading structure.

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A B

Figure 1. Severe dieback (A) of control (non-thinned fruit) tree in the spring following excessive fruiting during the previous growing season. Compare with a tree (B) on which 77% of the fruit were thinned during the previous growing season. Photographs made April 15, 1994 Crystal City, Texas.

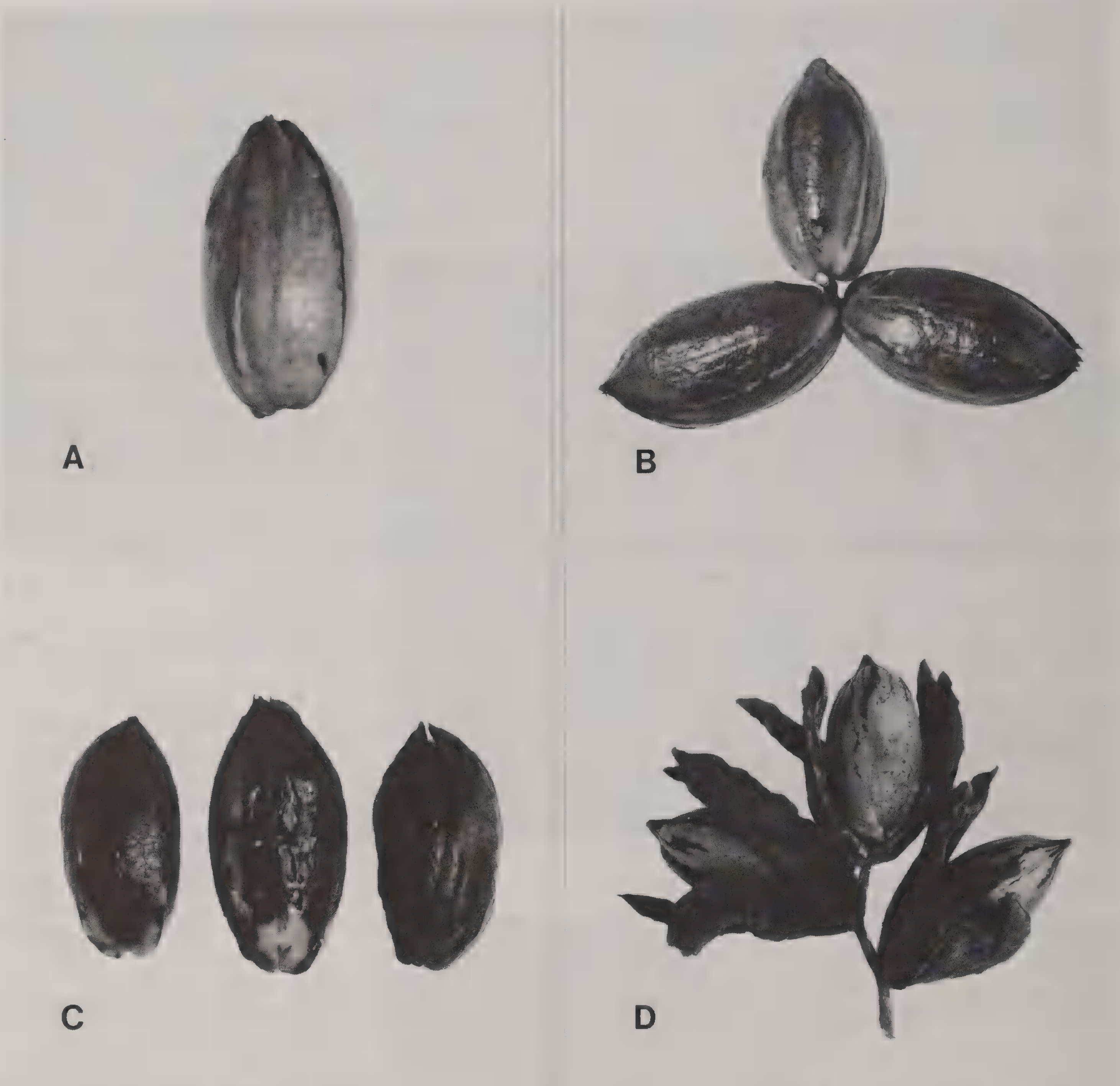

Figure 2. Stages of shuck decline: No decline (A), water-soaked (B), black shuck (C), premature shuck split, (D). The black and white photographs do not allow definitive distinction between the water-soaked and the black shuck stages of decline. In color, the exterior surface is a greenish tinge during the water-soaked stage in contrast to black during the black shuck stage.

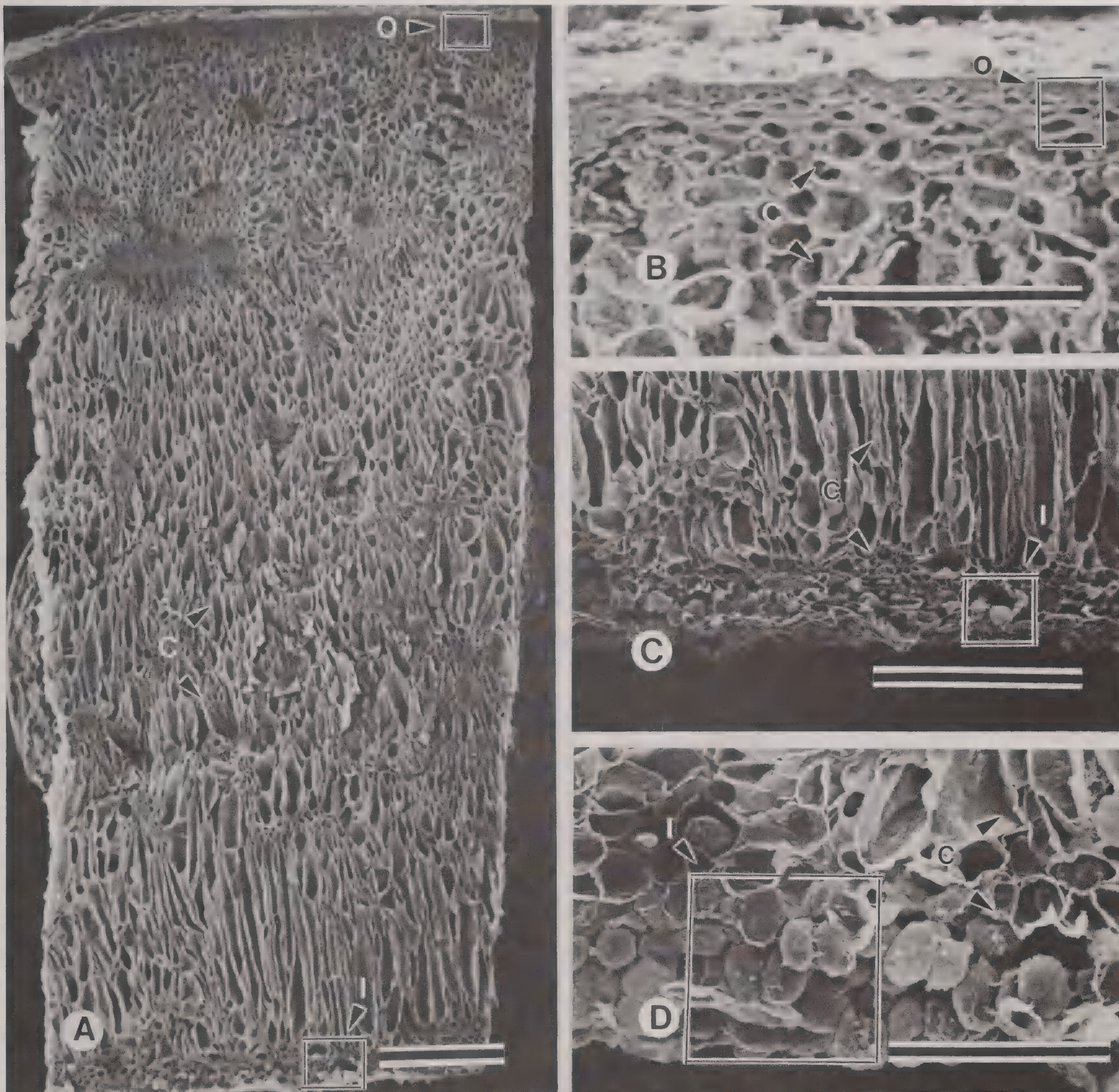

Figure 3. SEM of normal shuck. Cross section of entire shuck (A) demonstrates relative proportion of the outer, central, and inner tissue zones. Enlarged outer (B) and inner (C) zones of shuck. Further enlargement of inner zone (D) to show globules. The top and bottom sides of boxes define limits of indicated tissue zones. Abbreviations: o = outer, c = central, i = inner. Bars = 0.5 mm (A and C), 0.25 mm (B) and 0.2 mm (D)

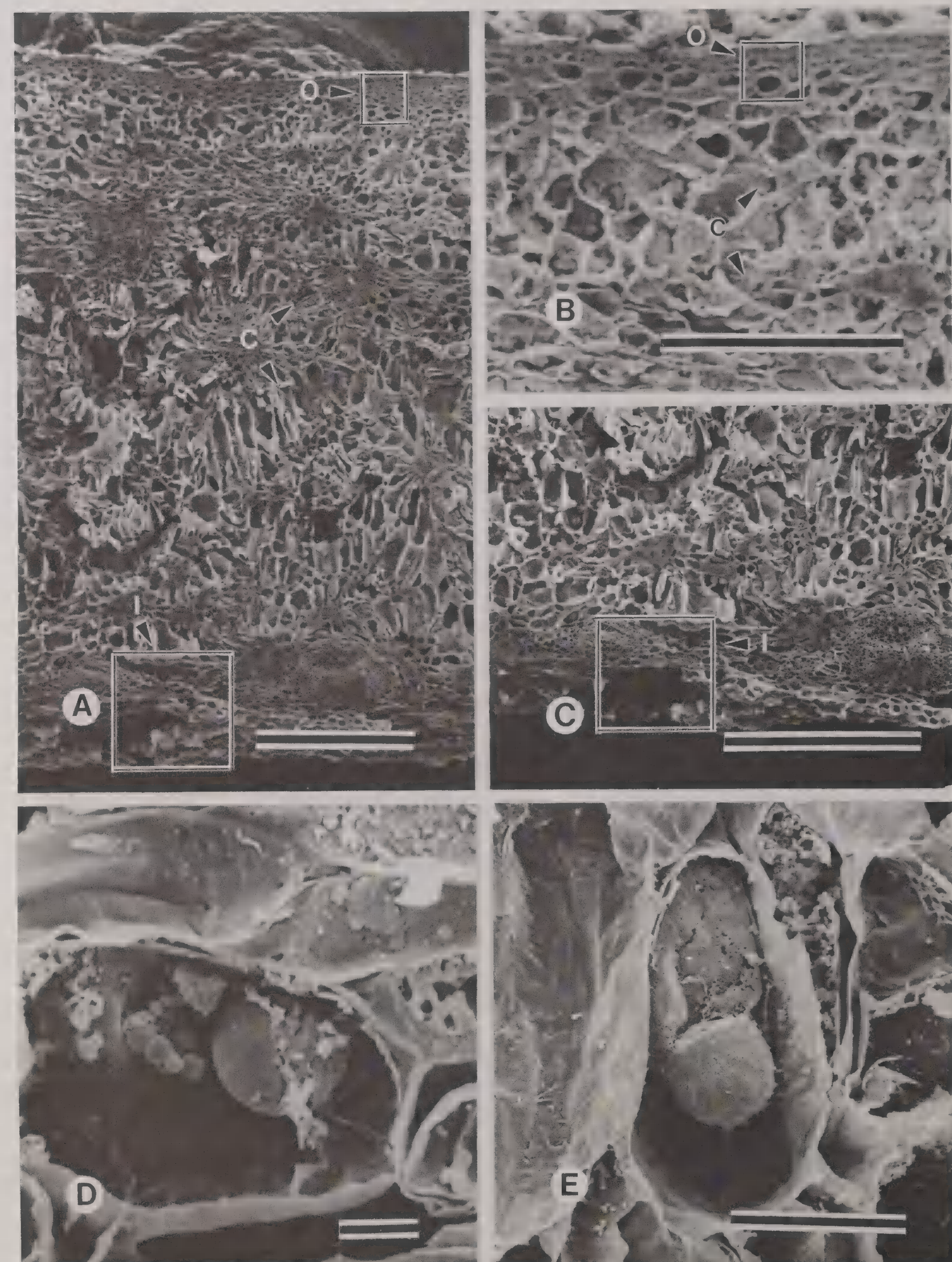

Figure 4. SEM of shuck in the black shuck stage of decline. Cross section of entire shuck (A) demonstrates relative proportion of the outer, central, and inner tissue zones. Enlarged outer (B) and inner (C) zones of shuck. The top and bottom sides of boxes define limits of indicated tissue zones. Globules present in cells of inner (D) and central (E) zone. Abbreviations: o = outer, c = central, i = inner. Bars = 0.5 mm (A and C), 0.25 mm (B), 10 μm (D), and 50 μm (E).

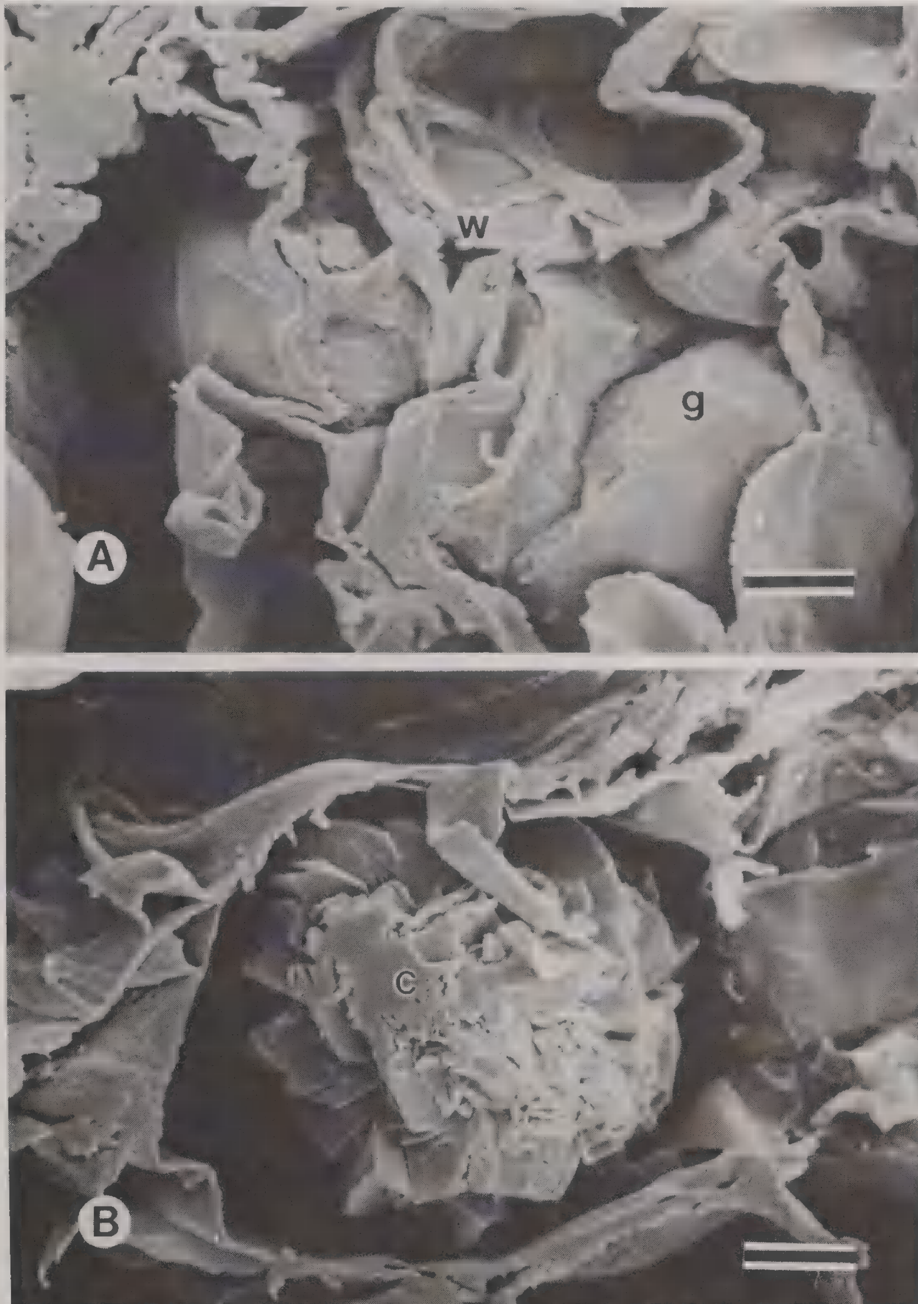

Figure 5. SEM of central zone cells with globules (A) and crystalline deposits (B) in a normal shuck following natural senescence. Abbreviations: w = wall, g = globule, c = crystalline deposit. Bars = 10 μm (A and B).

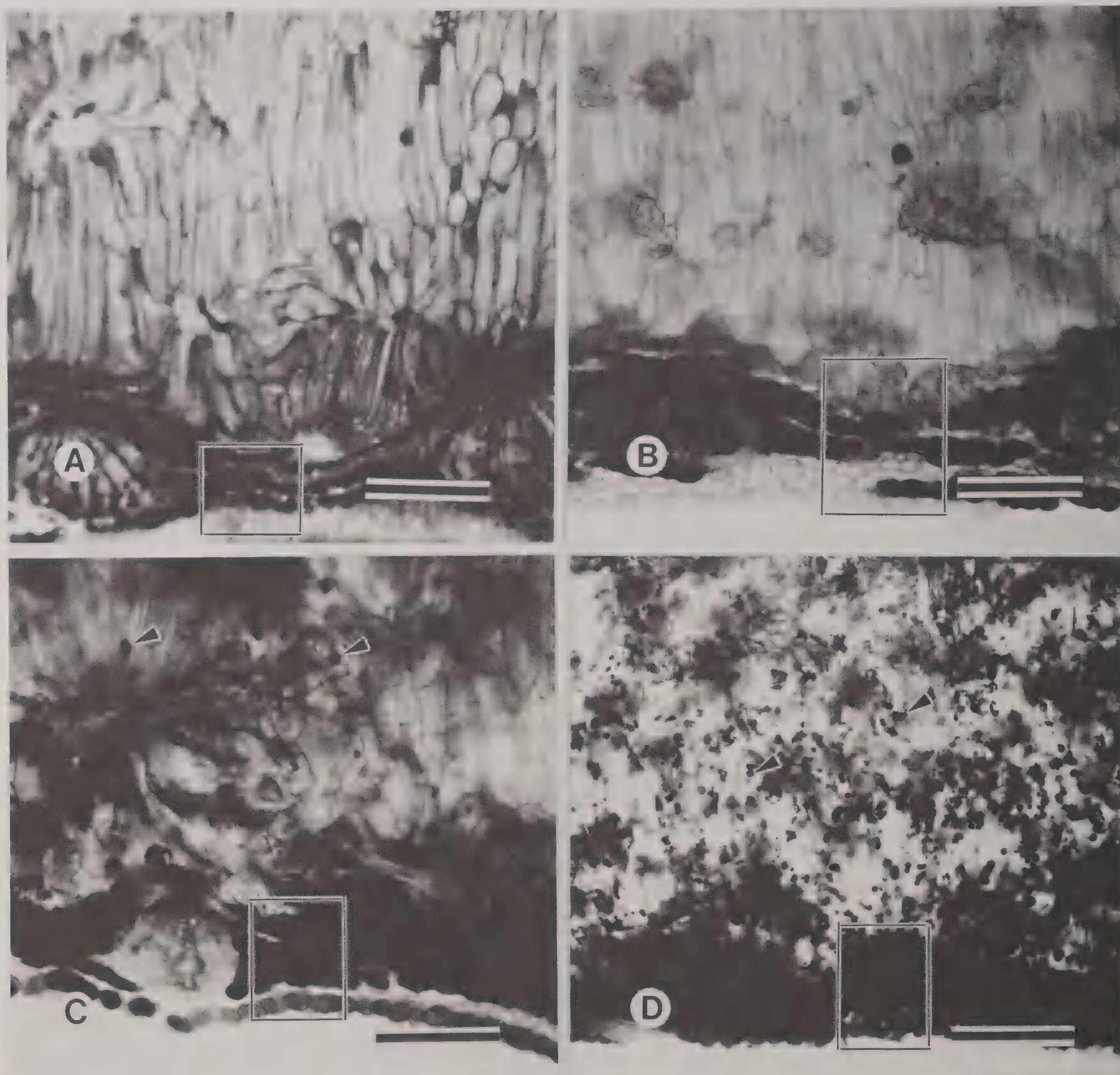

Figure 6. LM of normal shucks (A) and shucks with progressive stages of decline including fine black line (B), water soaked (C), and black shuck (D). The top and bottom sides of boxes define limits of inner tissue zone. Point indicates black globules. Bars = 100 μm (A - D).

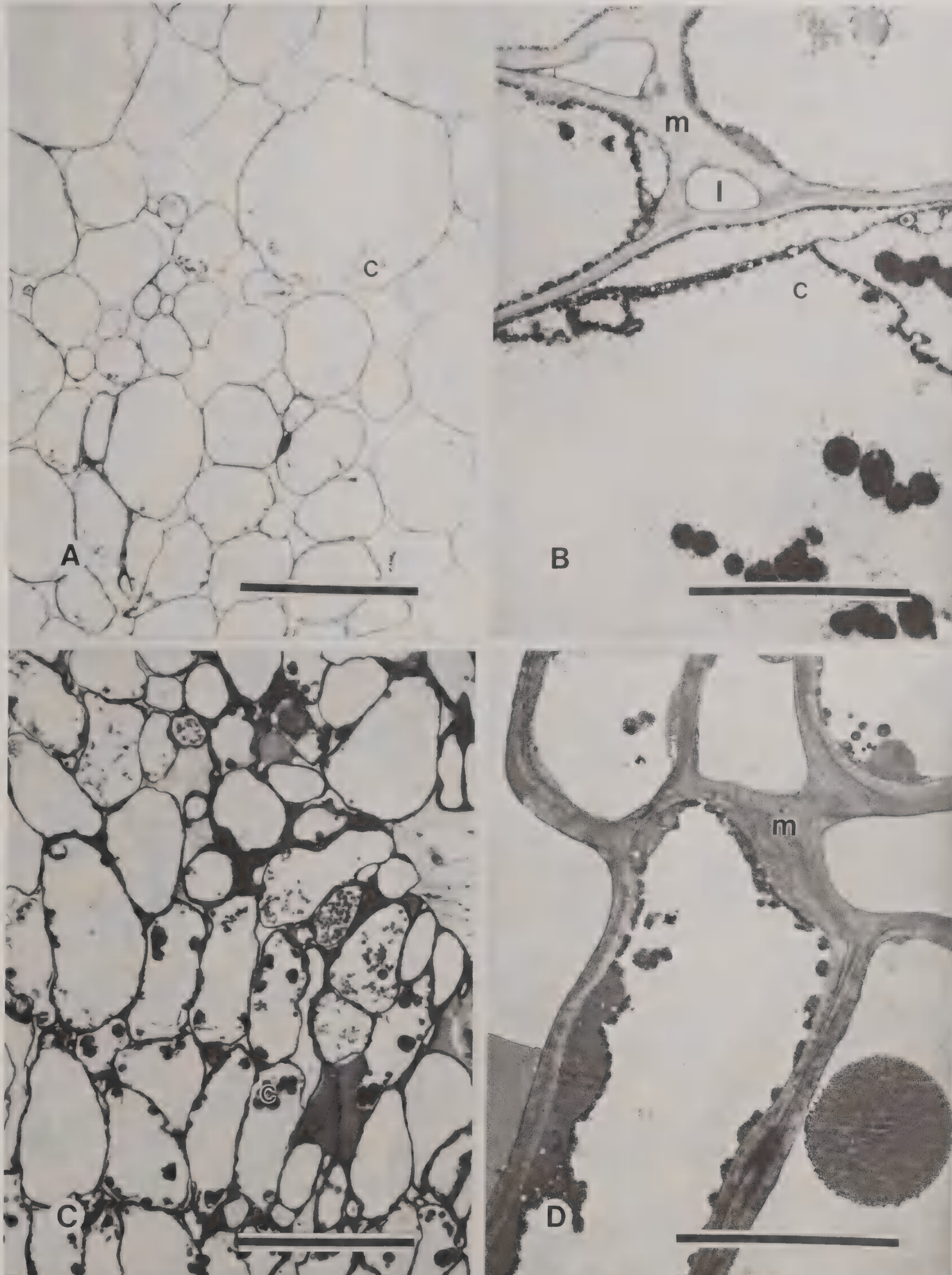

Figure 7. Normal shucks (A and B) and shucks with thin black line (C and D) examined by LM (A and C) and TEM (B and D). Abbreviations: l = lacunae, m = middle lamella, c = cytoplasm. Bars = 100 μm (A and C), 10 μm (B and D).

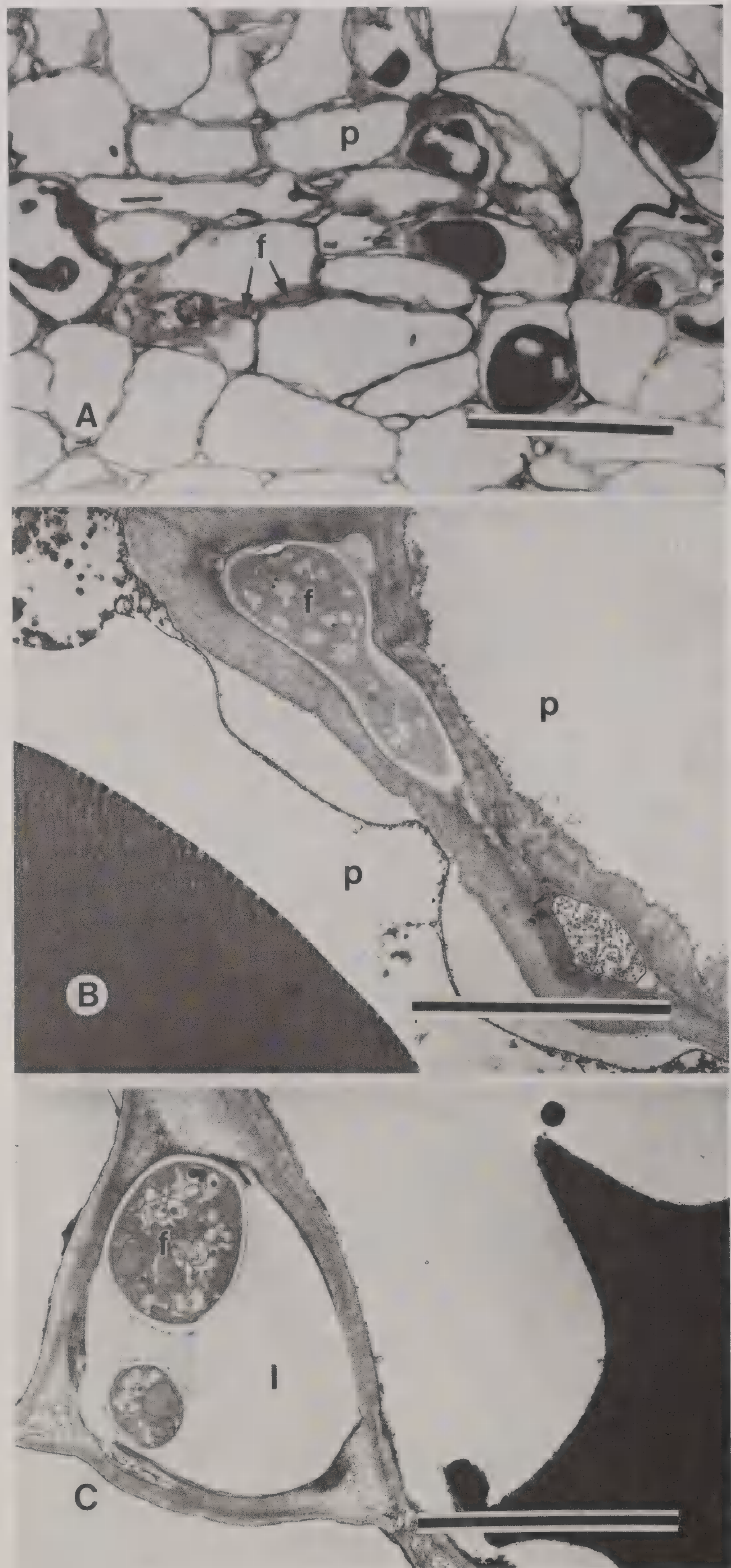

Figure 8. Water stage of shuck decline examined by LM (A) and TEM (B and C). Abbreviations: p = plant cell, f = fungal cell, l = lacunae. Bars = 100 µm (A), 10 µm (B and C).

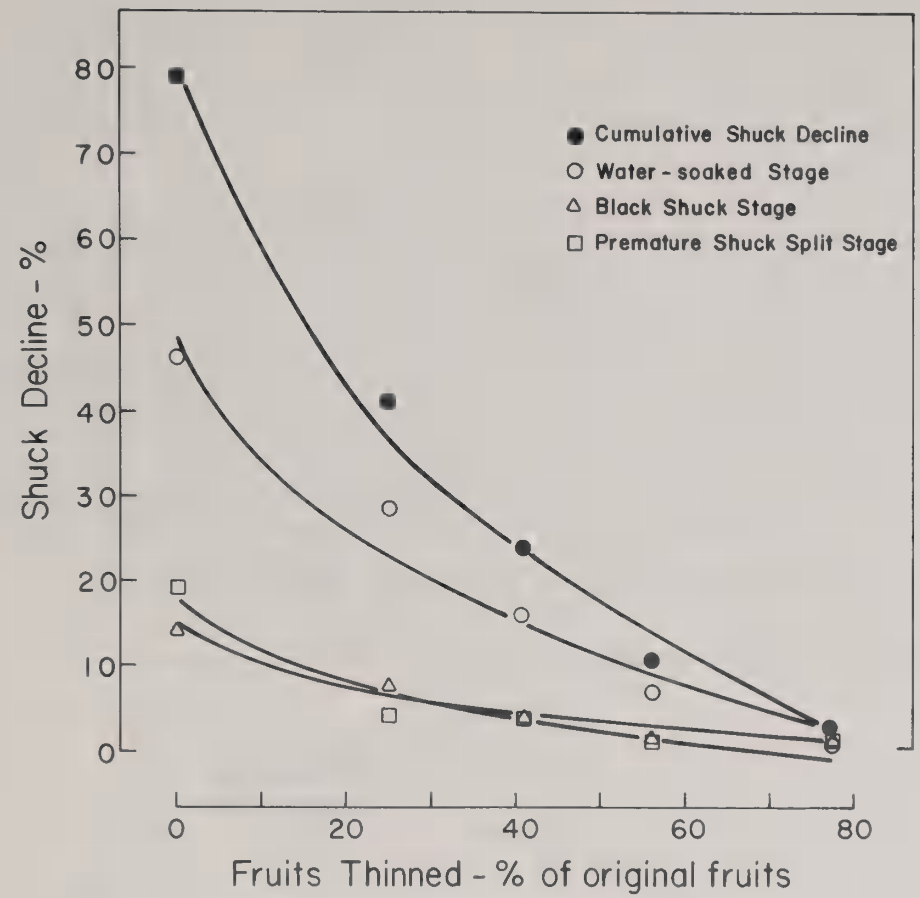

Figure 9. Shuck decline on 'Wichita' pecan fruits as a function of fruits thinned during the water stage of fruit development. The relationship of cumulative shuck-decline, water-soaked stage, black shuck stage, and premature shuck split stage to fruits thinned is described by $Y = 80.8 - 8.86 \sqrt{X}$, $r^2 = 0.796$; $Y = 48.8 - 5.23 \sqrt{X}$, $r^2 = 0.698$; $Y = 14.7 - 1.57 \sqrt{X}$, $r^2 = 0.633$; and $Y = 18.0 - 2.15 \sqrt{X}$, $r^2 = 0.600$, respectively. All regression coefficients are statistically significant from zero, $P = 0.05$.

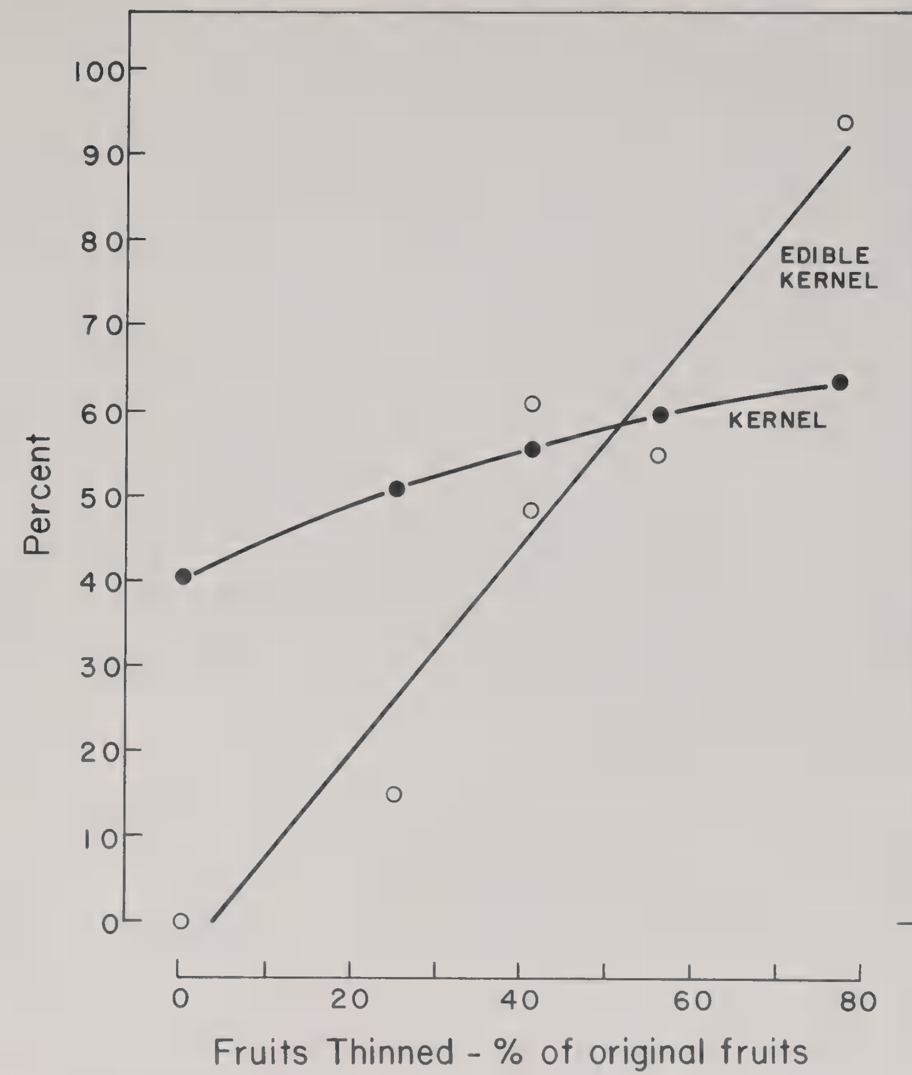

Figure 10. Percent kernel and percent edible kernel of 'Wichita' nuts as influenced by fruits thinned during the water stage of fruit development. The relationship of percent kernel and edible kernel to fruits thinned is described by $Y = 71.23[1 - 0.1e^{-0.018277(x - 80.59)}]$, $r^2 = 0.755$ and $Y = -5.66 + 1.22x$, $r^2 = 0.669$, respectively. All regression coefficients are statistically significant from zero, $P = 0.05$.

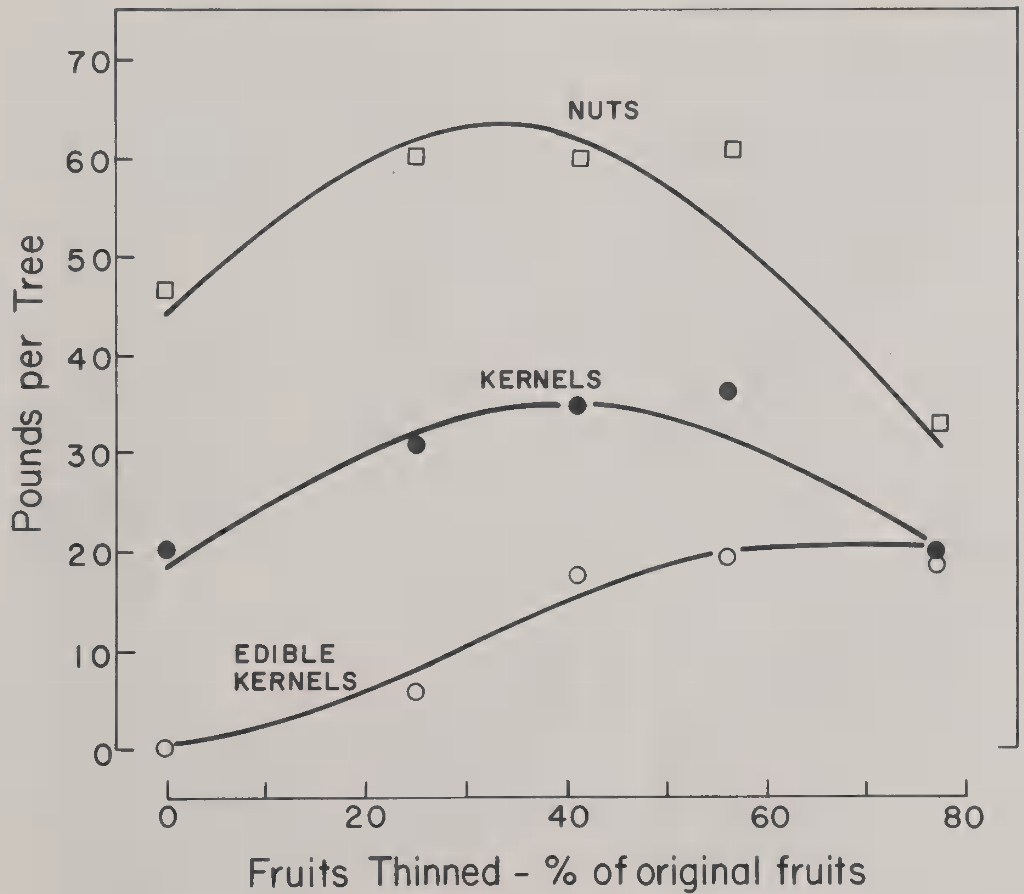

Figure 11. Nuts, kernels, and edible kernel of 'Wichita' pecan as a function of fruits thinned during the water stage of fruit development. The relationship of nuts and kernel to nuts thinned is described by $\sqrt{Y} = 4.16 + 0.0664X - 0.0009X^2$, $r^2 = 0.334$ and $\sqrt{Y} = 2.90 + 0.0549X - 0.0007X^2$, $r^2 = 0.356$, respectively. All regression coefficients are statistically significant from zero, $P = 0.05$. Data are for non-germinated nuts only (see Sparks et al., 1994).

FUNGI ASSOCIATED WITH TWIG AND LIMB DIEBACK OF PECAN IN CENTRAL GEORGIA

C.C.Reilly[1], K.L. Reynolds[2] and B.W. Wood[1]

Biotic and abiotic factors associated with twig and limb dieback of pecan were investigated. The dieback was most obvious after bud break and was characterized by moist, reddish-brown necrotic tissue about 0.5 to 1 cm in width beneath the bark which was slightly sunken and shriveled with the remainder of the necrotic tissue lighter brown and extending to the tip of the twig. Isolations of microorganisms were conducted from specimens obtained at the interface of healthy and necrotic tissue. Nine genera of fungi and two bacteria forming yellow or white colonies were consistently isolated from twigs and limbs with dieback symptoms. The frequency of isolation of a species of *Phomopsis* from fourteen cultivars of pecan was greater than 90%, whereas all other organisms were isolated at frequencies of less than 10%. Twig dieback was less than 10 cm on all cultivars prior to bud break in early March but increased to 30 cm or more by June. Pecan seedlings inoculated with the *Phomopsis* sp developed lesions similar to those on twigs with dieback. The fungus was isolated from the inoculated leasions. Trees subjected to water stress had significantly higher incidence of shuck disease and more twig dieback relative to new shoot growth the next season.

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SHUCK DISORDER, A PATHOLOGISTS'S VIEW

C.C. Reilly[1] and B.W. Wood[1]

Shuck disorder of pecan is characterized by browning and drying of the shuck, usually after shell hardening but well before the fruit is mature. The initial symptoms may develop either on the stem end, causing a condition of "stem end blight" (Brenneman 1991, Sanderlin 1989), on the blossom end, causing "shuck dieback" (Sanderlin 1989), or concurrent symptom expression on both ends (Reilly and Reynolds 1994). This disorder of shuck tissue leads to poor quality of the developing kernel. A similar group of symptoms occur during the disease Phytophthora shuck and kernel rot of pecan (Reilly et al. 1989, Reilly and Hotchkiss 1991, Hotchkiss and Reilly 1992) and should not be confused with shuck disorder considered in this discussion. The shuck disorder has been attributed to various causes including fungi, tree physiology and horticultural characteristics of specific cultivars (Reilly 1991, Reilly and Reynolds 1994, Sparks et al. 1994).

The shuck disorder does not occur without environmental and cultural components associated with it (Wood 1993). Excessive rainfall during the early and mid season, a condition highly favorable for plant disease development, spreads the spores of two fungi consistently found associated with shuck disorder (Reilly 1992, Reilly et al. 1993). These fungi are also the causal disease agents of fungal leaf scorch and pecan anthracnose (Rand 1914, Reilly et al. 1995), serious leaf diseases that can defoliate the tree in mid-September. Control of the diseases by fungicides is only partially effective during years in which rainfall is unusually heavy.

Tree stress induced by a heavy crop load, loss of tree vigor due to disease and insect pressure and mid- and late season drought will be manifested on the fruit as shuck disorder (Hotchkiss et al. 1993, Reilly et al. 1995). The earlier in the season the stress occurs, the more destructive the disorder is on crop quality and yield.

Two views exist as to the cause of shuck disorder. One considers that stress alone is the cause and that fungi are not involved (Sparks et al. 1994); the other, that fungi are involved and that increasing tree stress favors the pathogens, the greater the tree stress the earlier in the season the disorder appears (Reilly et al. 1995). From a plant pathologist's point of view these theories could be clarified by examining the development of the disorder under defined conditions.

The fungi involved must be demonstrated to be true pathogens of pecan fruit. Because there is a wide range of reaction to the disorder by the fruit of leading pecan cultivars, inoculation of the fruit under controlled conditions with the suspected fungi should produce similar results as observed in the orchard. Induced stress in an orchard should increase the severity of the disorder and the fungi should be isolated from fruit having the disorder. Through spore trapping and fungal isolation in the orchard the organisms should be shown to present throughout the growing season.

Fungal Pathogens: Two fungi have been consistently found associated with the shuck disorder. *Glomerella cingulata* (Ston.) Spauld. and Schrenk, first reported on pecan in 1914 as the cause of pecan anthracnose, a disease of leaves and fruit that has been found in many orchards recently in increased frequency (Brenneman and Reilly 1989, Rand 1914). A species of *Phomopsis* has been discovered as the cause of fungal leaf scorch, shuck necrosis, and twig dieback (Reilly et al. 1995). Inoculation studies with both fungi detected different levels of resistance in the fruit of 12 different cultivars (Reilly and Reynolds 1994). Moneymaker, Moore and Pawnee were severely affected by *G. cingulata*, whereas Desirable, Schley, and Stuart were tolerant. The fungus was isolated from the developing lesion. Inoculations with *Phomopsis* sp also yielded similar results with a differential reaction between the cultivars (Reilly and Reynolds 1994).

Sporulation and Orchard Presence: Both fungi involved in the shuck disorder are organisms requiring rain splash for spore dispersal. In our studies spores of both species have been detected throughout the growing season in pecan orchards (Reilly et al. 1993). Thus the fungi are present and capable of infecting the fruit prior to the onset of symptom expression. Fungal isolations throughout the season from healthy-appearing fruit and fruit with symptoms consistently reveal the presence of *G. cingulata* or *Phomopsis* sp or both fungi (Reilly et al. 1993).

Pecan trees that were differentially stressed by crop load and water management had significantly higher levels of shuck disorder in the most severely stressed treatment of heavy crop load and lack of water. Incidence of the *Phomopsis* sp in the treatment was significantly greater as evidenced by twig dieback the following season (Reilly et al. 1995).

Conclusions

Shuck disorder is actually a shuck disease complex involving at least 2 pathogens, *G. cingulata* and *Phomopsis* sp. Both organisms have latent periods from the time of infection to the time of symptom appearance. Symptom

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appearance is dependant on the level of stress on the tree with greater amounts of stress, causing the earlier symptom appearance. Disease severity, as yield loss or decreased quality, is dependant on the onset of symptoms; the earlier in the season symptoms appear, the more severe losses will become.

Reducing the level of stress in the orchard is a practical method of managing the shuck disease complex. Although fungicides presently available are not completely effective in controlling the shuck disease complex, they are effective against other diseases and do suppress fungal leaf scorch and pecan anthracnose to some extent. Thus, a well managed disease control program is vital in reducing the severity of the shuck disease complex.

Insect control is also vital in reducing tree stress. Aphid control should be managed in an aggressive manner, especially in years with a heavy crop load. The black aphid is a major concern because heavy infestation by this insect can cause leaf injury resulting in early leaf drop. The yellow aphid also can stress trees in the mid-season by removing large quantities of energy from the leaves, reducing photosynthesis, plugging phloem, and inducing the growth of sooty mold in the excreted honeydew. This in turn reduces the ability of the leaves to produce needed energy.

Water management in the orchard is probably the most important component of orchard stress management. During a heavy crop year the demand for water remains high throughout fruit development, and lack of water results in extreme tree stress, especially during kernel filling in September. Thinning of the orchard to increase tree spacing reduces tree competition for light and aids in disease control as well as increases the efficiency of water management.

Until more efficient fungicides become available or disease tolerant cultivars developed, orchard stress management is the key to reducing the potentially devastating effects of the shuck disease complex.

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DISTRIBUTION AND SPORULATION OF OVERWINTERED SCAB LESIONS ON PECAN SHOOTS

K.L. Reynolds

Overwintered lesions on pecan shoots are a major source of initial inoculum for epidemics of pecan scab, caused *Cladosporium caryigenum*, the most economically important disease of pecans in the southeastern U.S. Experiments were conducted to determine the distribution of lesions within the pecan tree canopy and the duration of spore production from shoot lesions. Samples of 1-year-old shoots from trees that had been treated with fungicide during the previous seasons were compared with shoots from trees that had been treated with fungicide during the previous season were compared with shoots from trees that received no fungicide. Samples were collected prior to budbreak in 1992 and 1993 from the upper, middle and lower thirds of the canopy of unsprayed trees. In both years, there were significantly more lesions per meter of shoot in the upper third of the canopy than in the lower two thirds, regardless of whether trees received fungicide treatment the previous year. Shoots in the upper third were also significantly longer and more vigorous than shoots in the lower third of the canopy. The duration of inoculum production from overwintered lesions was determined by quantifying production of conidia from lesions on samples of 1-yr-old shoots collected at regular intervals during the spring of 1994 and 1994. In both years, production of conidia declined steadily from June to August. In 1994, production of conidia from shoot segments was greatest from late March through mid-April. Spore production declined rapidly during the last two weeks in April. Although sporulation was greatly reduced during the summer, lesions continued to produce small numbers of conidia even as late as August.

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MARKETING PECANS: PRIMARY END USERS AND CONSUMPTION OF PECAN PRODUCTS

W.J. Florkowski and E.E. Hubbard[1]

ABSTRACT

Preliminary results of a nationwide pecan consumer study indicate that the frequency of pecan product consumption varies, but in general reflects the major pecan uses. Using three consumer characteristics (annual gross household income, education, and age) preferences for four pecan products were tabulated. The preferences were measured by the consumer assigned rankings. Cookies with pecan and ice cream with pecans were assigned different rankings with respect to each consumer characteristic. Separate promotional efforts may be needed to increase consumption of both products.

INTRODUCTION

Pecan marketing studies accumulated information on pecan postharvest handling and processing. Using survey techniques as a primary data collection instrument, the studies addressed utilization of pecans by major pecan end users and factors influencing pecan use in food manufacturing. Inconsistency in pecan supply, quality, and price were identified as major limitations to broader pecan use. This paper identifies processed pecan products preferred by consumers and relates consumer preferences to selected demographic and socio-economic consumer characteristics. The preliminary results are based on a nationwide survey of pecan consumers.

CHANGES IN PRIMARY PECAN USES

The average share of pecans in per capita consumption of tree nuts was 29% between 1960 and 1988. However, the share of pecans in the consumption of six major domestic tree nuts decreased steadily from 34% in 1960 to 19% in 1988. Regression of pecan share in tree nut consumption was a result of expanding production of other tree nuts, price competition, advertising and promotion, and limited use of pecans as a food component.

Pecan use is split between in-shell and shelled markets. In-shell pecan sales are primarily retail sales occurring during the holiday season. Shelled pecans are sold at retail outlets, in gift pack trade including mail order sales, at fund-raising events, and by wholesale distributors.

Retail sales and gift pack trade accounted for 39 percent of the pecan in-shell utilization (Woodroof, 1967). A more recent study suggested that retailers and gift packers utilized 32 percent of shelled pecans (Hubbard et al., 1990).

However, pecans have predominately been utilized as an ingredient in food manufacturing. Products containing pecans are manufactured by bakers, confectioners, ice cream and cereal manufacturers, and mixers and salters.

A relative decrease in pecan use by bakers did not affect their ranking as the primary pecan user (Table 1). A survey of southeastern bakers, conducted by the authors in 1991, indicated the type of baked goods in which pecans are used (Florkowski and Hubbard, 1994). Results indicate that retail bakers use pecans in a larger number of products and in a larger variety of forms than do wholesale bakers. Retail bakers used pecans in fruit cakes, pies, and cakes, while wholesale bakers used halves in fruit cakes, cakes, pies, and cookies.

Other large pecan users are confectioners and ice cream manufacturers. The use of pecans is reported by ice cream manufacturers (Table 1). The most common type of ice cream produced using pecans is butter pecan. This flavor competes well with other flavors according to many experts. Other ice cream flavors using pecans include praline pecan, cherry pecan, maple pecan, milk chocolate pecan, and pecan crunch. Primary use of pecans by confectioners is in manufacturing candy and chocolate covered nuts.

CONSUMER SURVEY

The objective of this paper is to identify consumer preferences for processed pecan products and relate those preferences to selected demographic and economic characteristics. Because the necessary data to research this issue are not readily available, a survey of consumers was designed and implemented.

The survey instrument consisted of a series of questions about respondents opinions concerning pecans and other nuts, frequency of consumption, taste perception, purchasing habits, etc. Respondents were also asked about their demographic and socio-economic characteristics.

Consumers identified preferences for processed pecan products by assigning a rank to each product on a provided list (Table 2). The list contained nine products produced by bakers, confectioners, and ice cream manufacturers who account for about one-half of shelled pecan use.

The nine products included: chocolate covered pecans, pecan flavored ice cream, cookies with pecans, pecans in

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roasted mixed nuts, pecan pies, cakes, roasted pecans, rolls with pecans, and other baked goods. The nine processed pecan products encompass the major type of products traditionally using pecans as an ingredient. The products listed are consistent with the primary pecan end users listed in Table 1. Furthermore, the list included more products manufactured by bakers because bakers remain the largest end user of pecans. In addition, shelled, raw pecans purchased by retail consumers are often used as an ingredient in home baked goods.

THE DATA

Data for this study were collected through a mail survey implemented in 1993. The survey covered all 50 states of the United States. The list of consumers was provided by the pecan industry for survey purposes.

The survey was preceded by a pilot test of the survey instrument. The pilot test results led to a few minor changes in the questionnaire. The survey was subsequently mailed to 861 consumers. A post card was sent as a reminder a week later followed by another questionnaire mailing. A total of 111 consumers could not be reached because of address change, etc. The survey response rate was 57.3 percent.

SELECTED CONSUMER CHARACTERISTICS

Market demand reflects consumer preferences. Preferences are shaped by many factors including cultural environment and demographic characteristics. Education influences the process of developing preferences by increasing consumer knowledge affecting food choices.

Education also increases the income earning potential of consumers. Consumers' income influences the degree to which a set of preferences can be exercised in the marketplace. Therefore, it is frequently difficult to separate the income effect from the education effect on consumer food selections and amounts purchased. In this paper, both education and income of consumers are presented in order to allow for comparisons how both characteristics could influence the preference for a pecan product. The relation of educational attainment level to preference for pecan products has not been explored in literature.

The annual gross household income serves as an indicator of preference and is not necessarily the perfect measure of taste preferences. The actual purchase is likely influenced by income elasticity of demand and, therefore linked directly to the amount of the discretionary income. Pecan products which are luxury goods in contrast to the necessities may be purchased on impulse, especially if sold in small packages or associated with the celebration of major holidays. Promotion and advertising may influence consumer beliefs and shape preferences affecting allocation of the limited discretionary income among possible purchases.

The demographic characteristic of consumers selected for this presentation was age. Age is a major factor influencing consumer purchasing behavior and attitudes toward food and food products. Age effect is shaped, among other factors, by the consumer's biological needs, acquired tastes, habits, and experience. Nut consumption studies have not addressed the impact of age.

RESULTS

Data collected through the survey were tabulated to identify preferences for a specific processed pecan product. Subsequently, the preferences expressed by assigned rankings were cross-tabulated against annual household income, schooling, and age of respondents.

Table 2 shows rankings assigned by respondents to the nine processed pecan products. The number of respondents ranking different products varied, suggesting that some respondents chose not to rank all listed products. Possibly, the number of respondents ranking a product indicates frequency of consumption, familiarity with the product or availability of the product in a given area.

Respondents ranked pecans in roasted mixed nuts, cookies with pecans and pecan flavored ice cream relatively higher than other products. Pecan pies and rolls with pecans were frequently ranked high followed by chocolate covered pecans and roasted pecans. Cakes with pecans and other baked goods were ranked lowest and least frequently.

This initial ranking of nine processed pecan products identified the highest ranked and most frequently ranked products. Pecans in roasted mixed nuts, cookies with pecans, and pecan flavored ice cream received the most primary rankings. When primary and secondary rankings were combined, these three products still ranked the highest. Pecans in roasted mixed nuts, cookies, and ice cream were also ranked most frequently in overall rankings.

The three most frequently ranked products and chocolate covered pecans were selected for further investigation in this study. The four items represent four different products and four most frequent pecan uses in food manufacturing.

ANNUAL HOUSEHOLD INCOME AND PECAN PRODUCT RANKINGS

Table 3 shows the distribution of respondents assigning a rank to a specific pecan product across four income categories.

Rankings assigned to chocolate covered pecans suggest a lack of strong preference, among all groups, for this

product. When primary and secondary rankings were combined, the lowest and highest income groups ranked this product higher than did the other two groups.

Pecan flavored ice cream was assigned the highest rank most frequently by persons with less than $40,000 annual household income. However, taking into account the primary, secondary and tertiary rankings indicate that the highest ranks were consistently assigned by respondents with $ 60,000 or higher household income. The relatively lowest ranks were assigned by respondents with $ 40,000 to $ 59,999 annual household income. This income group, however, seemed to prefer cookies with pecans assigning the highest ranks to that product. The remaining groups also ranked this product high suggesting that from the four products listed in Table 3, cookies with pecans were ranked high regardless of the respondent's household income.

A particularly strong preference for pecans in roasted mixed nuts was revealed by respondents with the highest income. Respondents with income between $ 20,000 to $ 39,999 and $40,000 to $59,999 ranked this processed pecan product higher than respondents with less than $ 20,000 annual household income. With the exception of the lowest income category, respondents from the other three income categories assigned pecans in roasted mixed nuts the number one rank more often than any of the other three products. In general, pecans in roasted mixed nuts were assigned the highest ranks followed by cookies with pecans, pecan flavored ice cream, and chocolate covered pecans.

EDUCATION AND PECAN PRODUCT RANKINGS

Table 4 summarizes the distribution of rankings assigned to four pecan products by the educational attainment level of respondents. Results suggest a lack of clearly defined differences in ranking chocolate covered pecans by respondents from the three education categories. It appears that respondents with 12 years of schooling or less ranked chocolate covered pecans slightly higher than respondents from the other two categories while respondents with 13 to 16 years of schooling ranked this product higher than those with 17 years of schooling or more.

Pecan flavored ice cream was ranked highest by respondents with 12 or fewer years of schooling. This group of surveyed consumers and consumers with the most education ranked this pecan product higher than respondents from the middle category (13-16 years of schooling).

Cookies with pecans seemed to be preferred more by respondents with higher educational attainment levels. Cookies with pecans were ranked as number one most often by individuals with 13-16 years of schooling. Respondents with the most years of schooling assigned cookies with pecans consistently high ranking. A similar trend was observed in ranking the next product, pecans in roasted mixed nuts. Although a similar percentage of respondents with the least and the most schooling ranked this product as number one, differences occurred in percentage of respondents assigning the second and the third rank. Specifically, respondents with most schooling (78 percent) assigned pecans in roasted mixed nuts ranks one through three.

Regardless of the amount of schooling, respondents consistently ranked pecans in roasted mixed nuts higher then the other three processed pecan products. Cookies with pecans were generally assigned slightly higher ranks than pecan flavored ice cream by all groups listed in Table 4 with the exception of those with no more than 12 years of schooling. Chocolate covered pecans were assigned lowest rankings.

AGE AND PECAN PRODUCT RANKING

Table 5 shows the distribution of assigned rankings according to six age categories. Chocolate covered pecans were ranked relatively high by the youngest respondents and relatively low by the next to the youngest group. This result should be treated with caution because of the small numbers of respondents falling in both categories. Among the remaining four categories, respondents 45-54 years old and 65 years and older ranked chocolate covered pecans higher than the other two groups (35-44 years old and 55-64 years old). However, respondents from the four oldest age categories also frequently assigned relatively low ranks to chocolate covered pecans.

Pecan flavored ice cream was ranked higher by respondents 45 years old and older, i.e., respondents belonging to the three age groups (45-54 years old, 55-64 years old, 65 years or older). The three groups of younger respondents also ranked this product relatively high except for 25-34 years old participants. However, because the sample contains relatively few respondents in the lower age categories, this result must be treated with caution. In general, all age categories ranked pecan flavored ice cream higher than chocolate covered pecans.

Cookies with pecans seemed to be assigned the highest ranks by the youngest respondents and by respondents 35-44 years old, 45-54 years old, and 65 years and older. Participants 55-64 years old were assigning relatively lower rank to cookies with pecans from among all age groups, even when compared to the 25-34 year old participants.

In contrast, the same groups of 55-64 years old respondents assigned the highest ranks to pecans in roasted mixed nuts than any other age category. All younger age categories, i.e., respondents 54 years old or younger also ranked this product relatively high. The oldest respondents ranked pecans in roasted mixed nuts relatively low.

Among all age groups, pecans in roasted mixed nuts received relatively highest rankings followed closely by cookies with pecans. Pecan flavored ice cream was ranked high by all except 25-34 years old and, to a lesser degree, by 35-44 years old. Chocolate covered pecans were ranked relatively lower than any other processed pecan product by all age groups. The relatively low ranking of chocolate covered pecans suggests that this product is less preferred by consumers and this fact should be taken into account when developing new pecan products.

CONCLUDING REMARKS

Preliminary results of a consumer survey suggest that respondents associated consumption of pecans with consumption of other nuts. Pecans in roasted mixed nuts were ranked consistently highest by respondents despite income, education, or age differences. This result suggests on one hand a cooperation in promotion of pecan consumption with other nut industries and mixed nut producers; on the other hand, the pecan industry may focus on searching for a product which could appeal to consumers and be specifically identified with pecans.

According to results presented in this paper, cookies with pecans and ice cream flavored with pecans represent two products which consumers ranked high. Furthermore, both products represent the use of pecans as an ingredient by two large industries. Both products, cookies and ice cream, seem to differ somewhat with respect to a group of consumers ranking them high if age, income, and education are considered. Therefore, two separate promotional efforts in cooperation with two different industries can be implemented simultaneously. Additional research and further analysis of the consumer survey data will provide insights about factors affecting pecan consumption.

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Table 1. Utilization of pecans by various types of end users, 1993 survey results

	Percent of utilization according to		
End user	Woodroof 1967	Powell 1975	Hubbard et al.[a] 1990
Bakers	36.0	25.5	25.0
Confectioners	19.0	21.9	12.0
Retailers	24.0	15.3	22.0
Ice cream manufacturers	—	4.9	7.0
Exports	—	4.8	NA[b]
Gift packers	15.0	4.7	10.0
Mixers & salters	—	4.1	NA
Other	—	9.2	6.0
In-shell	6.0	9.6	NA
Wholesale distributors	NA	NA	14.0
Food service outlets	NA	NA	4.0

[a] Shelled pecans as reported by Georgia shellers.
[b] NA = Not available.
Source: Florkowski and Hubbard, 1994.

Table 2. Ranking of processed pecan products purchased most often by consumers, 1993 survey results

Processed pecan product	Number of respondents ranking the product	Rank 1	2	3	4	5	6	7	8	9	Checked but not ranked
		percent									
Chocolate covered pecans	176	16	9	13	13	10	12	7	12	6	2
Pecan flavored ice cream	245	27	22	16	16	6	3	6	2	1	1
Cookies with pecans	295	29	26	21	7	8	3	4	0	0	5
Pecans in roasted mixed nuts	263	37	20	14	12	5	4	2	1	1	4
Pecan pies	240	16	23	16	16	7	7	3	3	4	5
Cakes	130	4	37	10	13	11	12	23	19	2	3
Roasted pecans	178	19	13	16	8	16	12	5	5	5	1
Rolls with pecans	190	14	18	14	12	8	7	10	11	4	2
Other baked goods	116	10	9	16	11	9	9	7	6	21	2

Table 3. Respondents' income distribution by rank indicating the frequency of pecan product consumption (1 = most often)

Ranked pecan products	Less than $20,000	$20,000 to $39,999	$40,000 to $59,999	$60,000 or more
	----------------------------	percent	--------------------------------	
Chocolate covered:				
1	19	11	17	17
2	11	8	5	12
3	17	11	17	40
4	14	11	0	22
5	6	14	12	9
6	11	14	12	12
7	8	8	7	7
8	6	14	22	9
9	8	8	7	2
Total[a]	100	100	100	100
Pecan flavored ice cream:				
1	32	32	22	24
2	19	19	22	26
3	13	18	10	23
4	15	15	22	13
5	4	2	12	7
6	5	8	2	3
7	11	6	5	3
8	7	2	2	1
9	0	22	0	
Total[a]	100	100	100	100
Cookies with pecans:				
1	34	27	32	30
2	27	28	30	24
3	16	22	21	26
4	6	10	3	9
5	13	7	8	7
6	3	1	3	3
7	0	3	3	0
8	0	0	0	1
9	0	0	0	0
Total[a]	100	100	100	100
Pecans in roasted mixed nuts:				
1	29	39	39	45
2	19	24	17	22
3	15	13	15	15
4	15	13	14	10
5	13	6	3	1
6	2	5	8	1
7	0	0	2	5
8	4	0	2	0
9	4	0	0	1
Total[a]	100	100	100	100

[a] The sum may not add to 100 due to rounding error.

Table 4. Respondents' level of education by rank indicating the frequency of pecan product consumption (1= most often, 9= least often), 1993 survey results

Ranked pecan product	12 years or less	13 - 16 years	17 years or more
	percent		
Chocolate covered:			
1	13	18	17
2	17	7	6
3	11	16	11
4	13	12	14
5	9	9	14
6	11	15	8
7	11	7	6
8	9	13	14
9	7	3	11
Total[a]	100	100	100
Pecan flavored ice cream:			
1	38	23	25
2	22	24	17
3	17	15	19
4	9	16	26
5	3	9	6
6	1	1	4
7	4	8	4
8	4	2	0
9	0	2	0
Total[z]	100	100	100
Cookies with pecans:			
1	29	34	24
2	28	21	40
3	18	24	21
4	8	7	8
5	4	9	5
6	4	3	2
7	3	1	0
8	0	1	0
9	0	0	0
Total[a]	100	100	100
Pecans in roasted mixed nuts:			
1	42	37	41
2	16	25	17
3	13	13	20
4	19	12	9
5	6	5	4
6	3	5	4
7	0	2	6
8	3	1	0
9	1	2	0
Total	100	100	100

Table 5. Respondents' age distribution by rank indicating frequency of pecan product consumption (1 = most often, 9 = least often), 1993 survey results

Ranked pecan product	24 years or younger	25 - 34	35 - 44	45 - 54	55 - 64	65 years or older
	percent					
Chocolate covered:						
1	17	0	16	16	9	23
2	33	0	8	11	13	6
3	33	0	8	21	13	11
4	0	0	16	16	13	11
5	17	20	11	8	3	13
6	0	60	19	5	13	9
7	0	0	3	8	13	9
8	0	0	16	13	13	11
9	0	20	3	3	13	6
Total[a]	100	100	100	100	100	100
Pecan flavored ice cream:						
1	44	17	9	28	22	36
2	22	0	26	23	32	15
3	11	17	16	26	15	14
4	11	17	26	10	11	17
5	0	0	7	8	4	8
6	0	17	2	3	4	2
7	11	33	9	3	6	3
8	0	0	2	0	2	3
9	0	0	2	0	0	1
Total[a]	100	100	100	100	100	100
Cookies with pecans:						
1	45	22	33	37	26	27
2	23	33	24	26	21	33
3	8	11	22	20	19	27
4	8	11	6	4	12	7
5	8	11	14	7	11	5
6	8	0	0	4	7	1
7	0	0	2	2	4	0
8	0	11	0	0	0	0
9	0	0	0	0	0	0
Total[a]	100	100	100	100	100	100
Pecans in roasted mixed nuts:						
1	36	29	43	35	51	32
2	36	29	20	24	13	18
3	0	0	17	9	14	20
4	27	14	9	15	12	12
5	3	0	2	4	5	7
6	0	0	4	7	0	6
7	0	0	2	7	0	1
8	0	14	2	0	0	1
9	0	14	0	0	0	2
Total[a]	100	100	100	100	100	100

[a]The sum may not add to 100 due to rounding error.

THE 1993 PECAN/TREE NUT MARKETING SEASON: AN OVERVIEW OF PRODUCTION, PRICES AND THE PECAN MARKET COLLAPSE

J.G. Peña[1]

The U.S. pecan market collapsed during the 1993/94 season after three years of record high prices. Whereas the preseason production forecast of 381 million pounds, the highest on record, may have had an adverse influence on the market, total supplies were not out of line to warrant the precipitous market drop. Historical pecan production/price relationships are examined, together than a review of the total U.S. tree nut situation. The purpose of this paper is to determine if the pecan market collapsed due to abundant supplies of pecans or did the market make an adjustment downward to the level competitive tree nuts after three years of record high prices.

Prices for pecans reached record highs during the 1991-92 period and the market collapsed during the 1993/94 season. While it's difficult to diminish the probable influence of a pre-season total U.S. pecan production projection of 381 million pounds, which would have been the highest on record, total supplies during this past season were not so far out of line to cause the market to drop to about the lowest trade levels of the 1980's. The total U.S. pecan production forecast for the 1993/94 season was subsequently adjusted down to 365 million pounds, but the market did not show signs of recovery to what would appear as a more equitable trade level.

Related to the pecan market, total annual U.S. tree nut production has almost doubled during the past twenty years. With regard to the 1993/94 pecan market season, the relationship of pecan markets to the price of competitive tree nuts should be reviewed - did the pecan market collapse due to abundant pecan supplies or did the market make an adjustment downward to the level of competitive tree nuts after three years of record high prices? Some market analysts considered recent pecan price highs to have been out of line in relation to the price of meats for other tree nuts. It, therefore, becomes important to analyze U.S. pecan production in relation to the production of total U.S. tree nuts.

The purpose for this paper is to review historical pecan and tree nut production/price relationships, the record price highs of the past three years as these prices relate to current pecan market trading levels and finally the relationship of recent pecan price highs to the price of competitive tree nuts.

A summary of the total U.S. tree nut industry, together with prices is provided to highlight relative volume and value of the major components of the total U.S. tree nut industry.

A summary of pecan production by state is included to highlight the U.S. pecan belt and to identify centers of production relative to market prices. Production and prices in Texas are compared to aggregate U.S. production/price information to measure the role of the pecan industry in Texas in relation to the U.S.

The paper consists of a graphical outline of the U.S. pecan situation as it compares to the total U.S. tree nut industry.

It should be noted that the production/price data for 1993 is based on USDA's July 8, 1994 supply/demand report.

PECANS

Graph 1 provides a graphical summary of the relative error of USDA's annual pecan production estimate comparing pre-season forecasts to final reports. It's important to review relative reporting errors and the possible influence that accurate production statistics may have on the market.

Up until the early 1970's, forecasts had a low margin of error when compared to final estimates. The margin of error increased during the late 70's-early 80's but it wasn't until around 1986 when the margin of error increased to 10-20 percent. Higher margins of error, together with the continuing alternate bearing characteristic of pecan production have increased uncertainty and risk in the pecan market. The margin of error gradually increased starting in 1989 to over 20 percent in 1992 but decreased substantially this past season.

It appears doubtful, however, that USDA's relative error had a large influence on the market. Subsequent downward adjustments of the initial pre-season forecast for the 1993/94 season suggest that a large portion of the crop may not have been harvested due to low mid-season market price bids.

The apparent recent trend to wide production swings may have a greater influence on market prices than the rate of reporting error. In this regard, it's important to note the role of native pecan production to alternate year production levels as compared to the more stable production of improved varieties.

BUYER CONCENTRATION

Recent pecan industry trends to concentrate to fewer buyers controlling larger volumes of pecan production may allow quicker market access, adjustments and market impact. Buyer concentration in recent years influenced the vulnerability of recent record high market prices to make price adjustments to a market level closer to competitive

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tree nuts. Fierce competition and adjustments to the number of buyers and volume per buyer appears to have had a detrimental effect on the pecan market.

PECAN SUPPLIES/MARKET PRICE

Graph 2 provides a summary of U.S. production of native and improved pecan varieties comparing total production to in-shell prices received during 1980 to 1993. Please note that during the period of record high prices, native pecan production was low in 1990 and 1992, followed by relatively high levels of production, thereby amplifying the alternate year bearing characteristic of the pecan industry.

Total pecan production decreased during 1988-1990 period after showing steady increases from 1984 to 1988. Prices jumped starting in 1989 when production dropped to about 250 million pounds, followed by even a smaller crop of 205 million pounds in 1990. This means that in two years, production dropped 125 million pounds, down over 40 percent from a production level of 330 million pounds in 1988 when prices dropped to the near record lows of the last thirty years. Production rebounded in 1991 to 299 million pounds and whereas prices dropped slightly, it appeared that the pecan market had jumped to a new level of trade.

It's difficult to surmise whether decreased production in 1990 and 1992 (the lowest production level since 1976) with a normal production level during 1991, the in-between year, may have created enough scarcity to account for all or part of the recent record high prices. It is, therefore, necessary to compare total available supplies during those years to determine the relationship of total supplies to prices.

TOTAL PECAN SUPPLIES

Graph 3 provides a summary of pecan production and carry-in stocks by year at the start of each season by combining USDA's August estimate of carry-in stocks with the final report's estimate of annual production from 1980 to 1993. The U.S. aggregate composite price for improved and native varieties is included in this graph. Whereas it appears that carry-in stocks have remained at a relatively constant average of about 125 million pounds, stocks showed a slight decrease during the period of record high prices. Carry-in stocks for the 1993/94 season at 85.3 million pounds were the lowest since 1981.

It therefore appears that the trend toward wider production swings is associated with annual production levels. Some producers associate the recent increase in the volume of imports to unstable markets.

Imports are added in Graph 4 to provide an aggregate summary of total pecan supplies. A quick review of Graph 4 indicates that the market, after showing a steady rise during 1983-1986 when total annual supplies remained below 400 million pounds, prices dropped significantly in 1987 and 1988 as total supplies exceeded 400 million pounds.

Prices again rebounded when total supplies dropped below 400 million pounds indicating the market sensitivity to the 400 million pound level of supplies.

Although part of the recent pecan price highs can be attributed to lower supplies, the market appears to be responding to other influences. The upward price trend toward the recent record highs started in 1989 when total supplies were about 440 million pounds. Prices dipped in 1991 as total supplies increased to over 460 million pounds and peaked during the abrupt supply drop to about 330 million in 1992, the lowest total supply level since 1980. Total supplies in 1992 when prices reached record highs were actually 54.3 million pounds higher than the price peak in 1980. The composite weighted average price in 1992 of $1.45/lb was almost double the comparable composite price of $0.78/lb in 1980. Even when adjusted for inflation, price highs of 1992 appear to have been responding to other market factors.

PRODUCTION IN GEORGIA

With regard to the production lows during the 1990-1992 period and this season's large crop, it's important to note production in Georgia (Graph 5). Production in Georgia which accounts for about 37 percent of total annual production, dropped to record lows in 1990 followed by a resurgence to about 100 million pounds and a drop to a low of 30 million pounds in 1992, the year of record price highs. Production in Georgia jumped to 150 million pounds in 1993, one of the highest crops on record.

U.S. PECAN BELT

It's important to identify centers of pecan production in order to asses their role in the total pecan marketing scheme.

Although the U.S. pecan belt consists of 15 mostly southern states from California to North Carolina (Graph 6), four states, Georgia (45%), New Mexico (15%), Texas (16%) and Arizona (10%) comprise 83 percent of the total average U.S. production of improved varieties during the last twelve years.

Five states (Graph 7) produced 90 percent of the total average U.S. native pecan production during the last twelve years. Texas (29%) dominates native pecan production, followed by Georgia's seedling production (20%), Oklahoma (16%), Louisiana (16%), and Alabama (8%).

Three states (Graph 8) provided two-thirds of the total average U.S. pecan production during the last twelve years. Georgia (36%) dominates the industry followed by Texas (20%) and New Mexico (11%).

PECAN VALUE

USDA's July 1994 report of the value of the pecan industry in the U.S. in 1993/94 indicates a significant decline as a result of price drops (Graph 9).

The average annual farm value of the U.S. pecan industry dropped to about $214 million after peaking at over $300 million in 1991.

U.S. TREE NUTS

It's important to review total tree nut production in relation to prices and their possible/probable effect on pecan prices. Production and price relationships of competitive tree nuts, especially almonds and walnuts, should be reviewed carefully to see if, for example, abnormally large supplies of these nuts caused their respective prices to collapse. thereby dragging pecan prices down.

Total U.S. tree nut production has experienced unprecedented growth during the past twenty years, especially during the 1980's. Although total tree nut production peaked this past season at almost 1.6 billion pounds, expansion of the industry appears to have levelled off with annual average production of 1.45 billion pounds, about double the average annual production of the mid-70's.

MACADAMIA NUTS

Production of macadamia nuts (Graph 10) appeared to have levelled at about 50 million pounds per year during the late 1980's. Production appears to have dropped to about 48 million pounds per year during the last three years, after unprecedented growth during the 1980's. Current production has grown about 220 percent over average annual production of about 15 million pounds during the mid-1970's.

Farm prices for in-shell macadamias reached record highs in 1987-90 of about $0.80-$0.85/lb, but have dipped to about $0.70/lb during the past two years.

With an average farm value of about $40 million, the U.S. macadamia industry is about one-fifth the size of the U.S. pecan industry.

PISTACHIO NUTS

Pistachio production (Graph 11) has suffered one of the most extreme alternate bearing problems of the U.S. tree nut industry. The industry appears to be gaining better control of this problem during the past two years. Production peaked this past season at about 150 million pounds, nearly double the production level of two years ago. The industry also experienced over 200 percent growth during the 1980's.

Prices for pistachios appear to follow almost a classic example of traditional supply/demand forces. Prices did not fluctuate as widely during the past two seasons since production appears to have stabilized. Prices were fluctuating at about $1.30/lb, but appear to have levelled off at about $1.20/lb.

With an average value of about $74 million, the U.S. pistachio industry is about one-fourth the size of the U.S. pecan industry.

ALMONDS

California is now the world's dominant producer of almonds. U.S. almond production is one of the largest tree nut industries in the country (Graph 12). The industry experienced unprecedented growth during the 1980's. With recent average annual production at about 550 million pounds, the industry has grown 175 percent from average annual production of about 200 million pounds during the mid-70's.

Although the U.S. remains the largest single market for California almonds, U.S. consumption has grown steadily from 37,500 tons annual in the early 1970's to well over 100,000 tons currently. The industry has made major efforts to expand foreign markets. Foreign markets, as a group, have grown faster than the domestic market. About 60 percent of the 1991-92 crop was sold on the export market.

According to a feature article in the November-December 1993 issue of the California Agriculture magazine, major markets for California almonds have developed in Japan and the European Economic community (EC) countries of Germany, France, Italy, the Netherlands and the United Kingdom. Essentially, all the almonds consumed in Japan are supplied by California, but the largest single export market for California almonds is Germany. Germany accounts for close to 30 percent of total California almond exports. Since 1980, California has supplied 70 percent of the German almond market. California enjoys similarly large market shares in France (58.5%), the Netherlands (56.8%) and Great Britain (81.7%).

Except for record breaking price peaks, such as in 1986 with a very short crop, and the 1993/94 season with a relatively short crop and excellent demand, average farm prices for almonds have hovered around $1.00/lb shelled since the mid-80's. NOTE: Almond production, supply and prices are reported on a shelled basis, compared to other tree nuts which are generally reported on an in-shell basis.

In relation to pecans whose market collapsed during the 1993/94 season, it's interesting to note that even though the 1993 crop was far from a short crop, prices of almonds continued to rise, a rise which began in 1990.

With a total farm value of over a half billion dollars in annual sales, the U.S. almond industry is a market pace setter in the tree nut industry.

WALNUTS

With average annual production at about 450 million pounds, U.S. walnut production (Graph 13) is also one of the major tree nut industries. The industry experienced about 50 percent growth during the 1980's.

Walnuts almost compete directly with pecans.

Farm prices for walnuts were about $0.50/lb in-shell during the mid- to late-80's and it appears that prices are increasing, following the almond lead.

With an average annual farm value of about $230-$250 million, the U.S. walnut industry is about the same size as the U.S. pecan industry.

FILBERTS

With average annual recent production of 50 to 60 million pounds (Graph 14), the U.S. filbert industry is one of the smaller tree nut commodities in the country. U.S. filbert production also almost doubled during the 1980's.

Farm prices for filberts during the mid-80's averaged $0.40-$0.50/lb in-shell. It appears, however, that the price trend is down, driven apparently by unprecedented growth to about 75 million pounds in 1993. It's interesting to note that prices dropped to about $0.25/lb in 1992, the lowest level since 1972, but bounced back in 1993, the year of record high production.

With an average annual farm value of $14-$18 million, the U.S. filbert industry is about half the size of the pecan industry in New Mexico.

PECANS

The U.S. pecan industry experienced dynamic changes during the past 20 years (Graph 15). Production declined significantly during the early 70's, followed by unprecedented growth during the late 70's. Wide price swings, loss of income tax advantages, and other factors caused the industry to display undecided growth during the early 80's. The market crashed during 1987-88 as the industry was showing signs of resurgent growth. The market crash apparently influenced a production decline during 1988-90, which in turned influenced prices to reach record highs.

A resurgence of wide production swings since 1989, compared to relative stability during the mid-80's, has had an adverse effect on the market. For example, production declined to about 166 million pounds in 1992 to the lowest level since 1974 followed by an estimate 365 million pounds this past season, the second highest level on record (1963's crop of 376.4 million pounds was the highest on record).

This past season, abnormally high production in relation to record high prices of the last three years, which many buyers considered out of line in relation to prices for competitive tree nuts, undoubtedly had an adverse influence on the market.

Under the current production/price structure, the farm value of the U.S. pecan industry is about $214 million, up from about $140 to $150 million during the mid 1980's.

TREE NUTS

Current annual total U.S. tree nut production, at about 1.6 billion pounds (Graph 16), has doubled during the past 20 years from average annual production of about 800 million pounds in the mid-70's.

The average annual farm value of the total U.S. tree nut industry is over one billion dollars. It is interesting to note that more than two-thirds of this value is concentrated in California, compared to the pecan industry which stretches over 15 states.

PRICES FOR COMPETITIVE TREE NUTS

Finally, an in-shell farm price comparison of the three major competitive tree nuts, almonds, walnuts and pecans (Graph 17), indicates that although almonds and pecan trade at a slightly higher plane than walnuts, all three competitive commodities trade at comparable levels in-shell.

The price differential between almonds, walnuts, and pecans widen, however, when the farm value of almond, walnut and pecan meats are compared during the record price highs for pecans during the 1990-92 period. Graph 18 provides a comparative price summary of the equivalent farm value of shelled almonds, walnuts and pecans.

It appeared that the price of pecan meats may have gotten out of line during the record price highs when compared to the two major competitors.

At first glance, it appears that the farm value of pecan meats adjusted downward during the 1993/94 period to be more in line with farm prices of meats from competitive tree nuts. A more detailed historical price analysis, however, indicates that pecan meats have enjoyed a 20-30 percent price premium over their competitors.

Using an average of prices during the 1982-1985 period as a price base for all three commodities and adjusting this average for inflation using the Consumer Price Index (CPI) would indicate that the farm price for pecan, almond and walnut meats should average $2.08, $1.32 and $1.75 per pound, respectively. Whereas pecan meats were above the CPI adjustment during 1989-1992, the period of record high prices, pecan dipped significantly below the adjustment in 1993. Both almonds and walnuts fall above the adjustment in 1993.

It therefore appears that other, not readily apparent, market forces influenced the pecan market crash of 1993.

SUMMARY

Record high price hikes for pecans during the 1990-92 period, a period of short supplies followed by a very large crop in 1993, abundant supplies of lower priced competitive tree nuts, and an apparent concentration of buyers in the pecan industry, appears to indicate that the pecan market was vulnerable to a major downward price adjustment to a level which is more competitive with other tree nuts.

In-shell farm prices for the major tree nuts have, for the most part, remained at relatively the same level throughout the late 1980's. The price for pecans widened when compared to almonds and walnuts during the record high market price years during 1990-1992. This widening of prices is particularly true when comparing the equivalent farm value of almond, walnut and pecan meats.
The farm price for in-shell pecans, and especially pecan meats, made a major downward adjustment during the 1993/94 season, but it appears that other forces, besides normal supply/demand relationships, affected the market this past season.

The concentration of buyers and volume of pecans processed by few buyers during the 1980's had an influence on the market. Fierce competition and the restructuring of buyer concentrations, together with the second highest pecan crop on record, also had an adverse influence on the market during the 1993/94 season.

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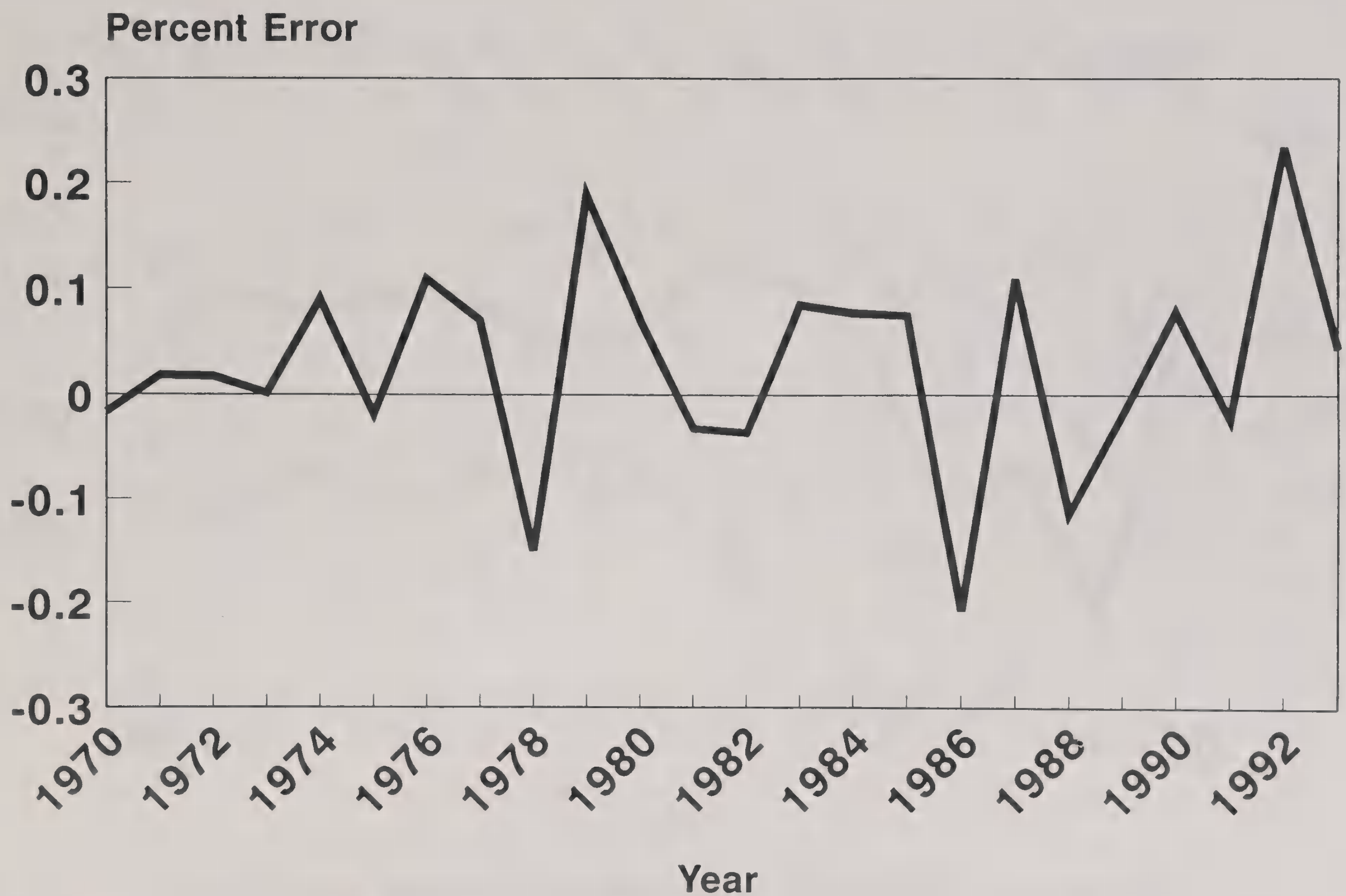
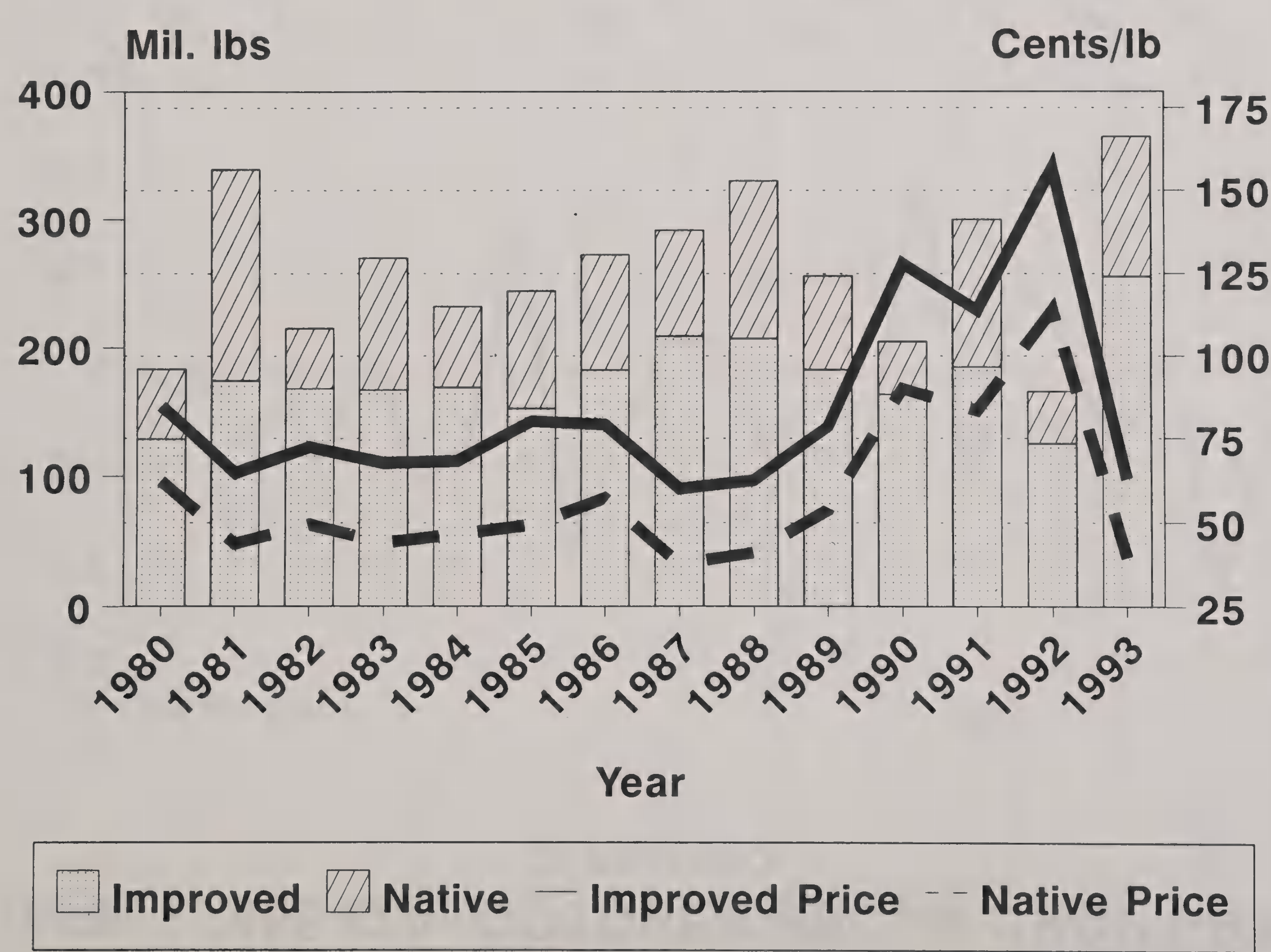
GRAPH 1. U.S.D.A. OCTOBER PECAN CROP ERROR
1970-1993



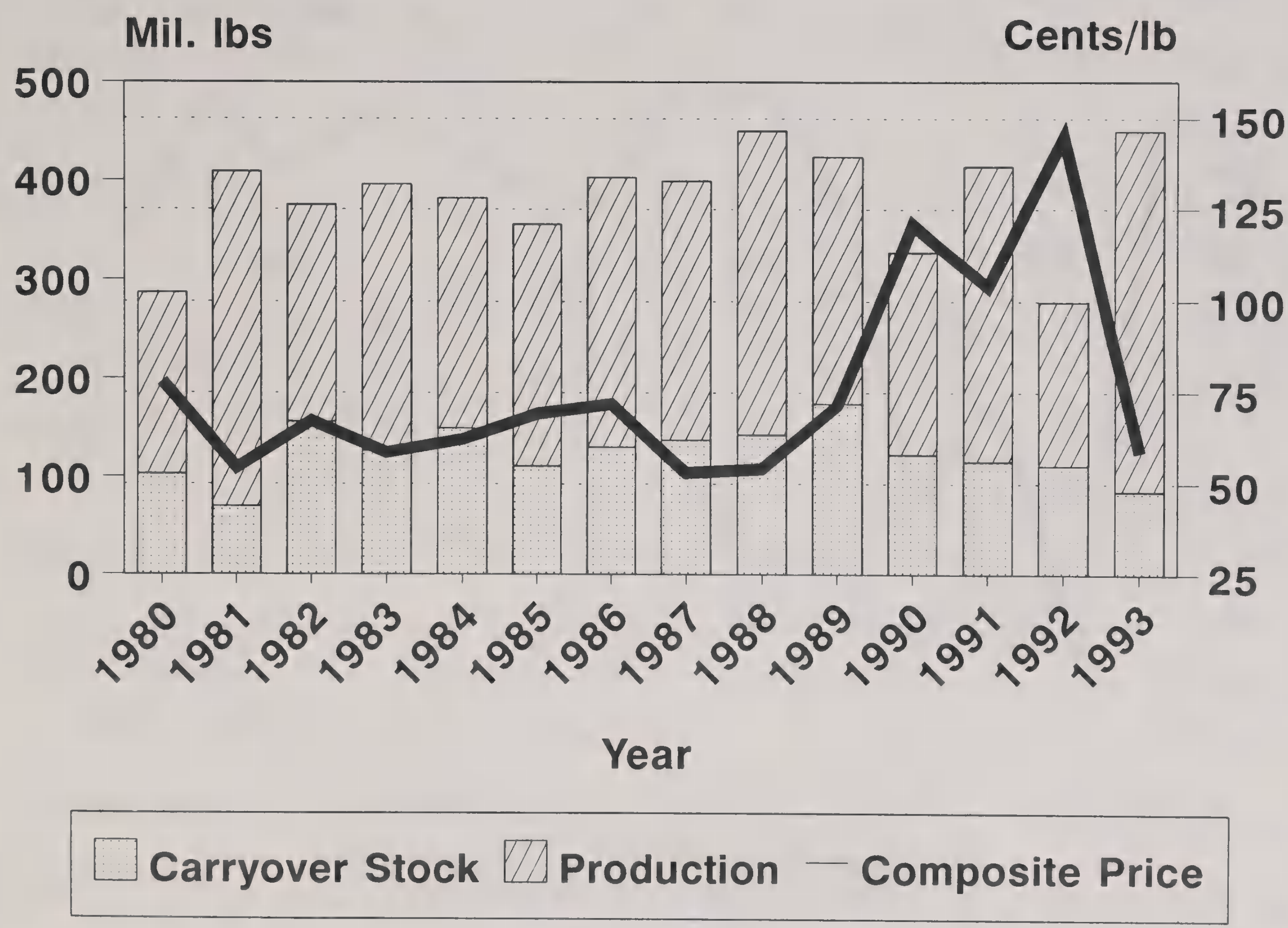
ERROR OF EST. AS % OF FINAL RPTED. PROD.

Graph 2. U.S. IMPROVED AND NATIVE PECANS 1980-1993

Production and Average Price Received (In-shell)

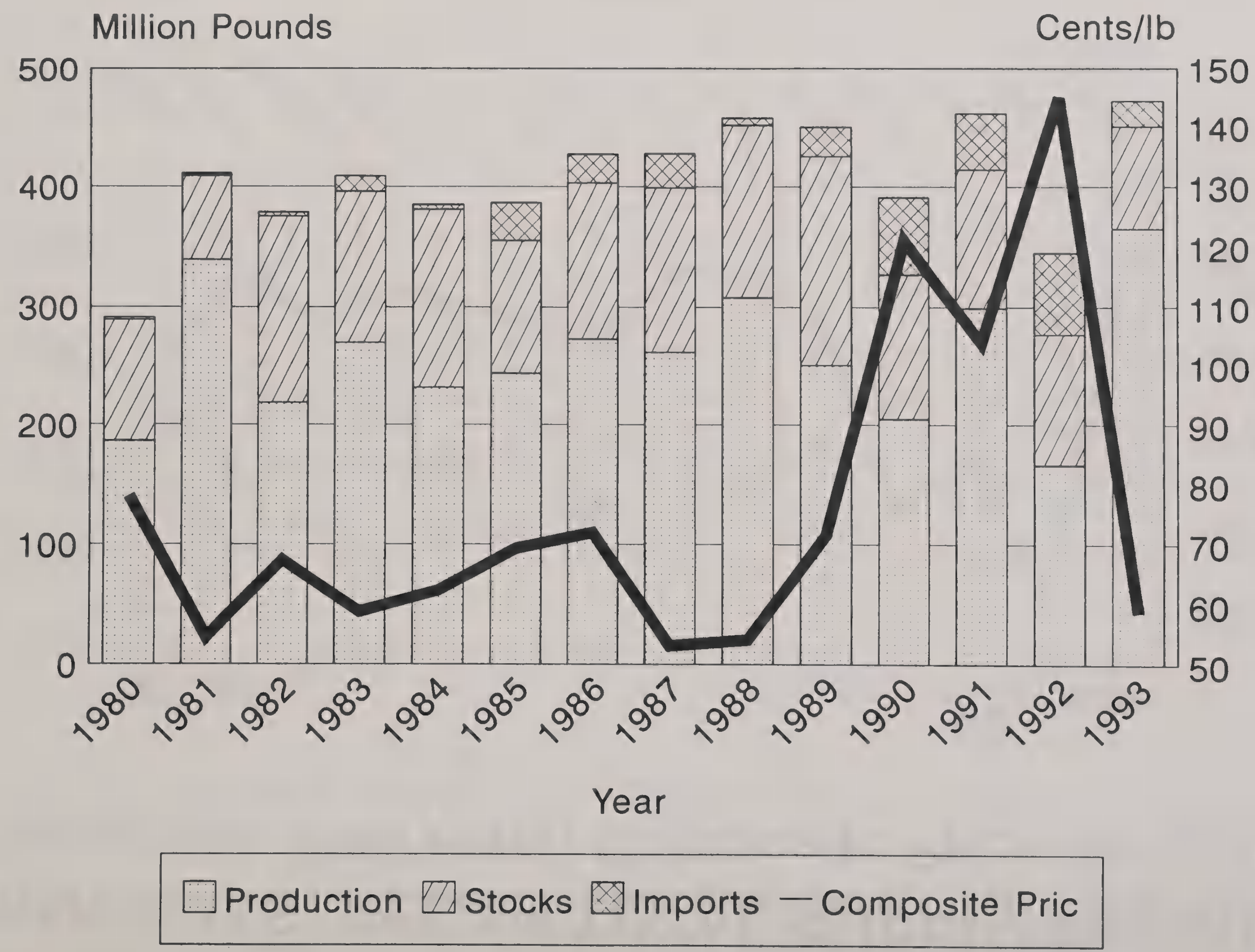


Graph 3. U.S. PECAN TOTAL SUPPLY 1980-1993
Production, Carryover, Composite Price (In-shell)



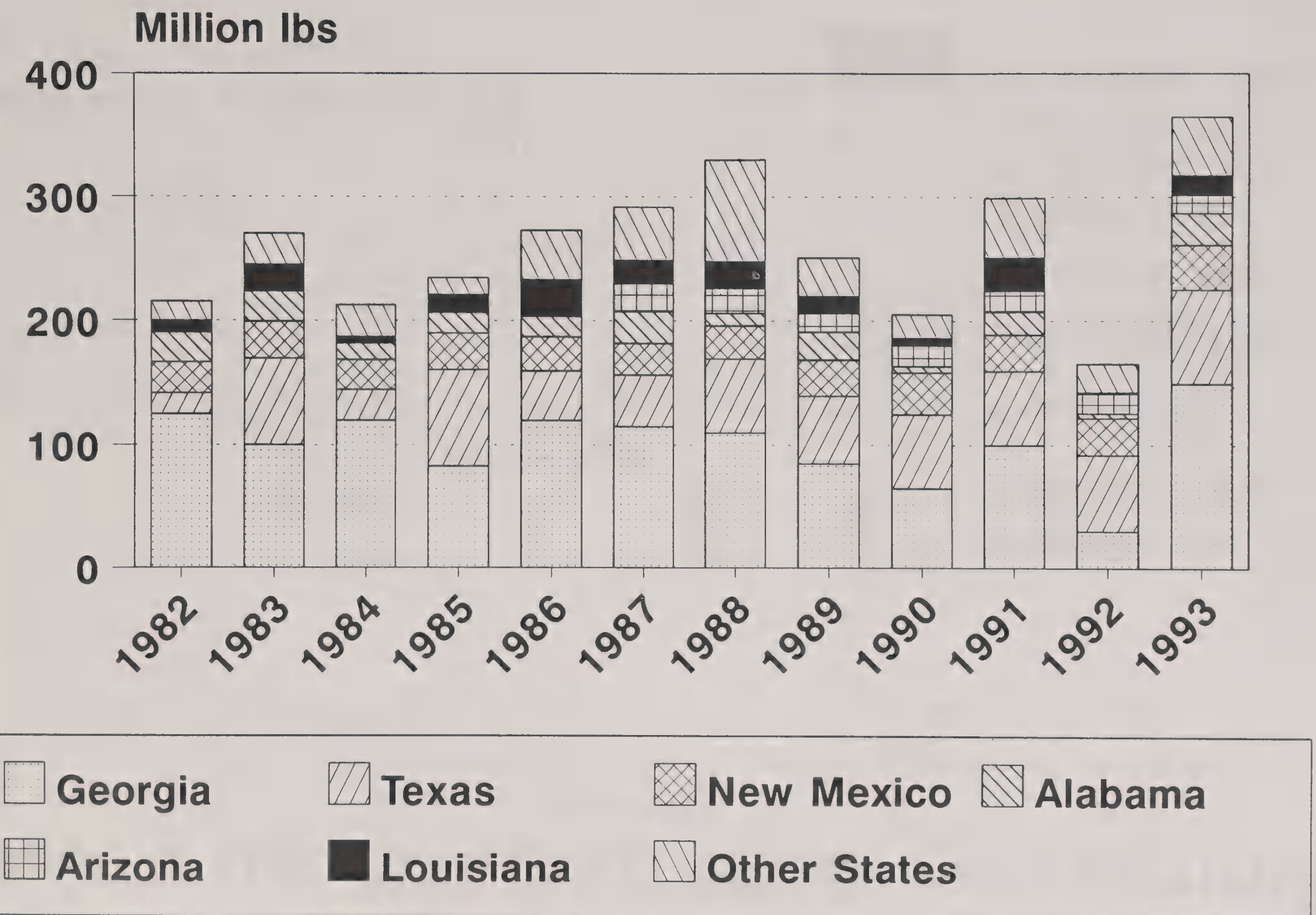
Graph 4. U.S. Pecan Production, Imports, Stocks & Composite Price

Marketing Year 1980-93 - In-Shell Basis

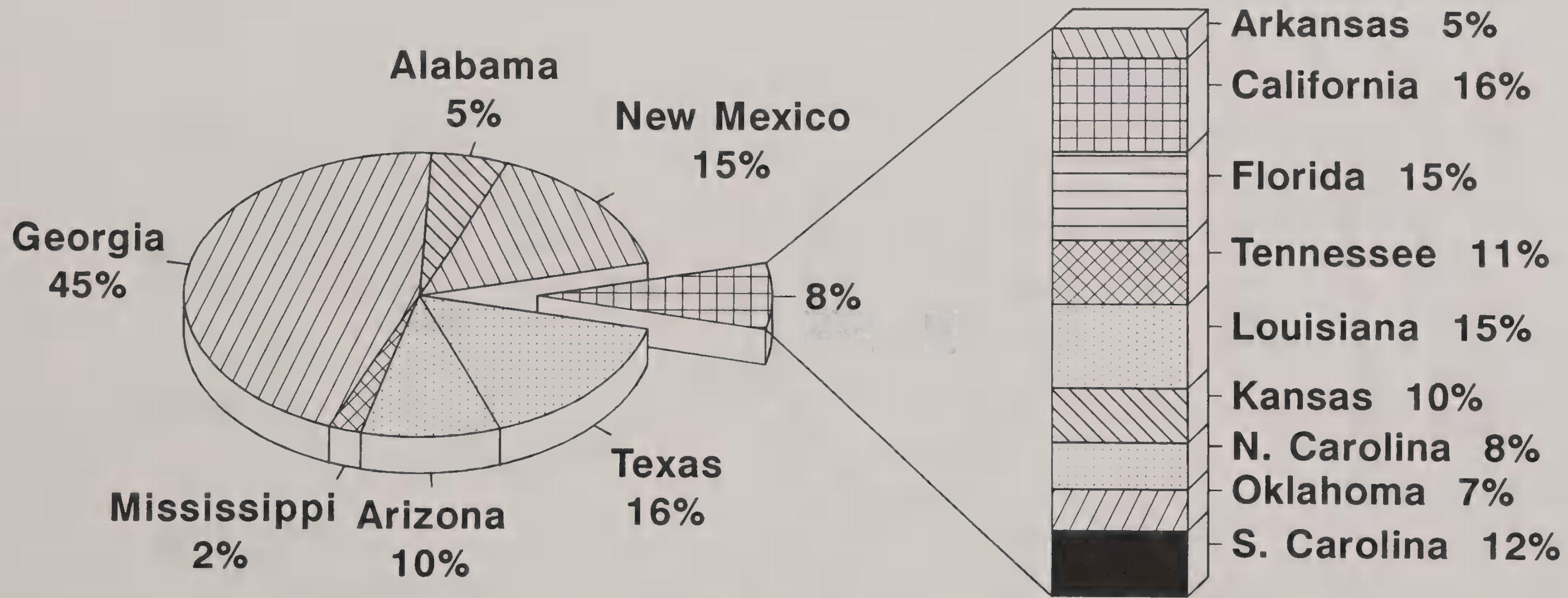


GRAPH 5. U.S. PECAN PRODUCTION BY MAJOR REGION

1982-1993

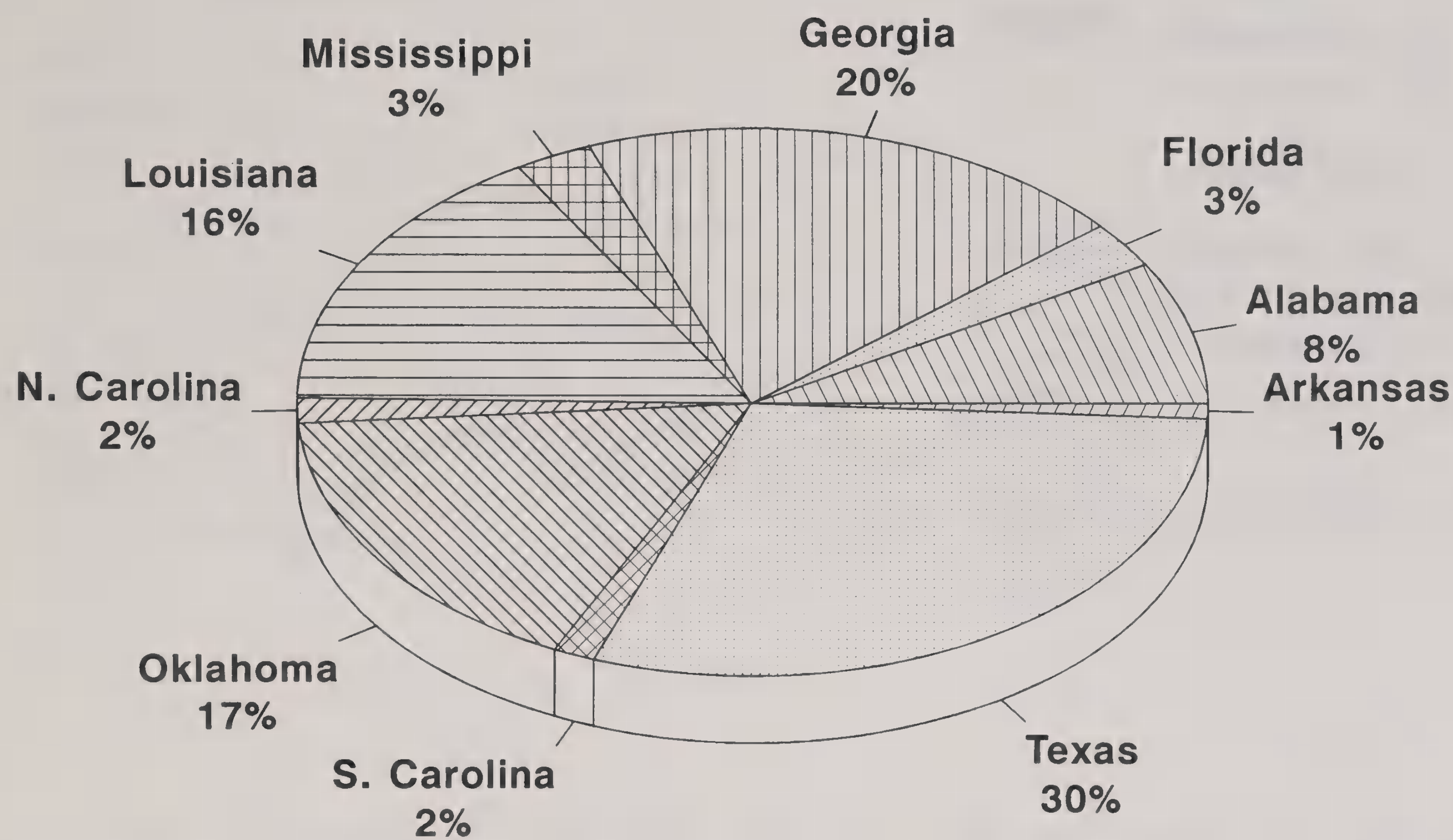


Graph 6. U.S. IMPROVED PECAN PRODUCTION
1982-93



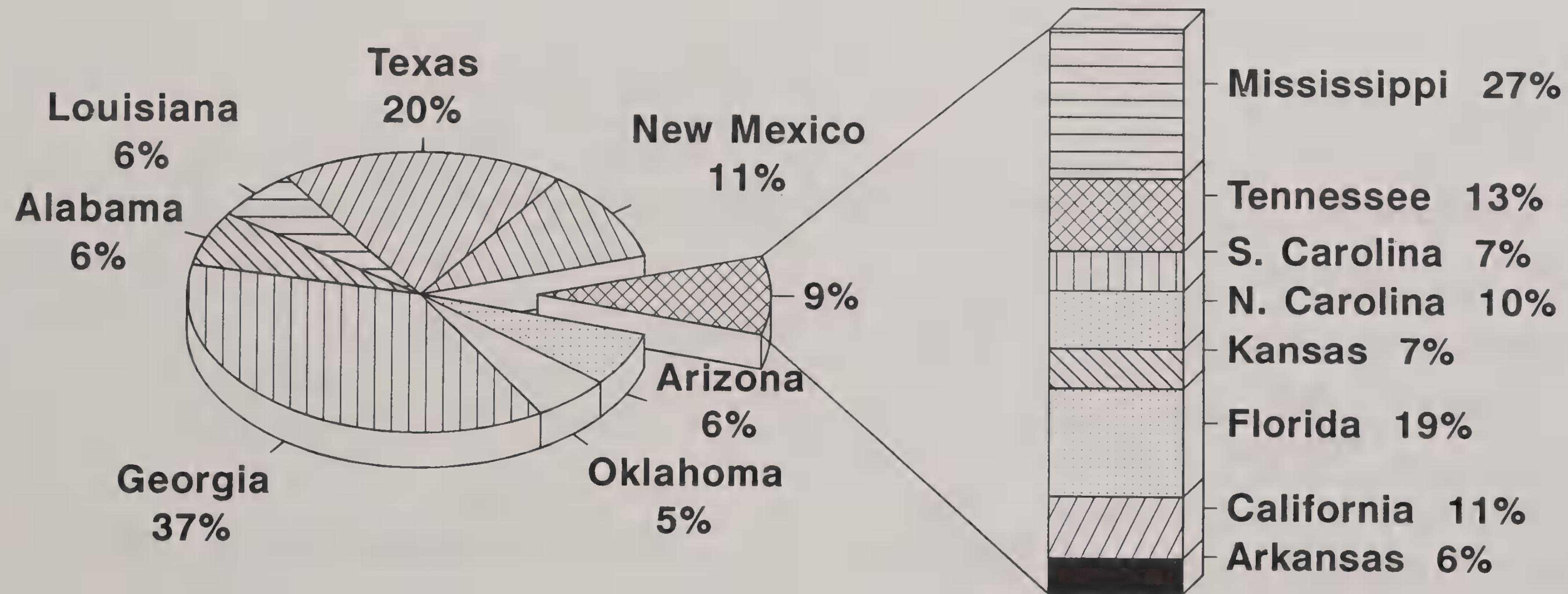
Twelve Yr. Ave. 180,728,000 lbs

Graph 7. U.S. NATIVE PECAN PRODUCTION
1982-1993



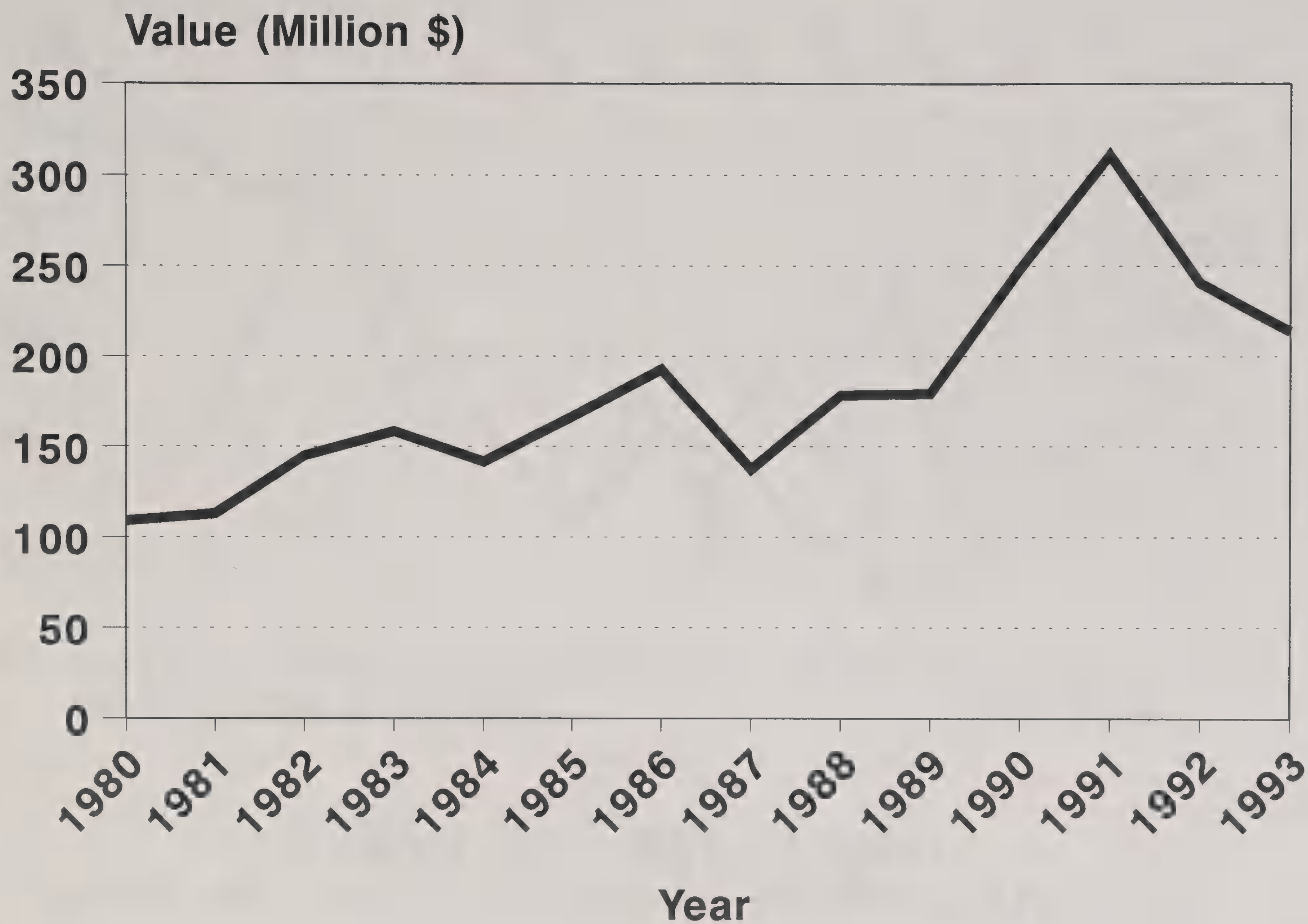
Twelve Yr. Ave. 81,648,000 lbs

Graph 8. U. S. ALL-PECAN PRODUCTION
1982-93

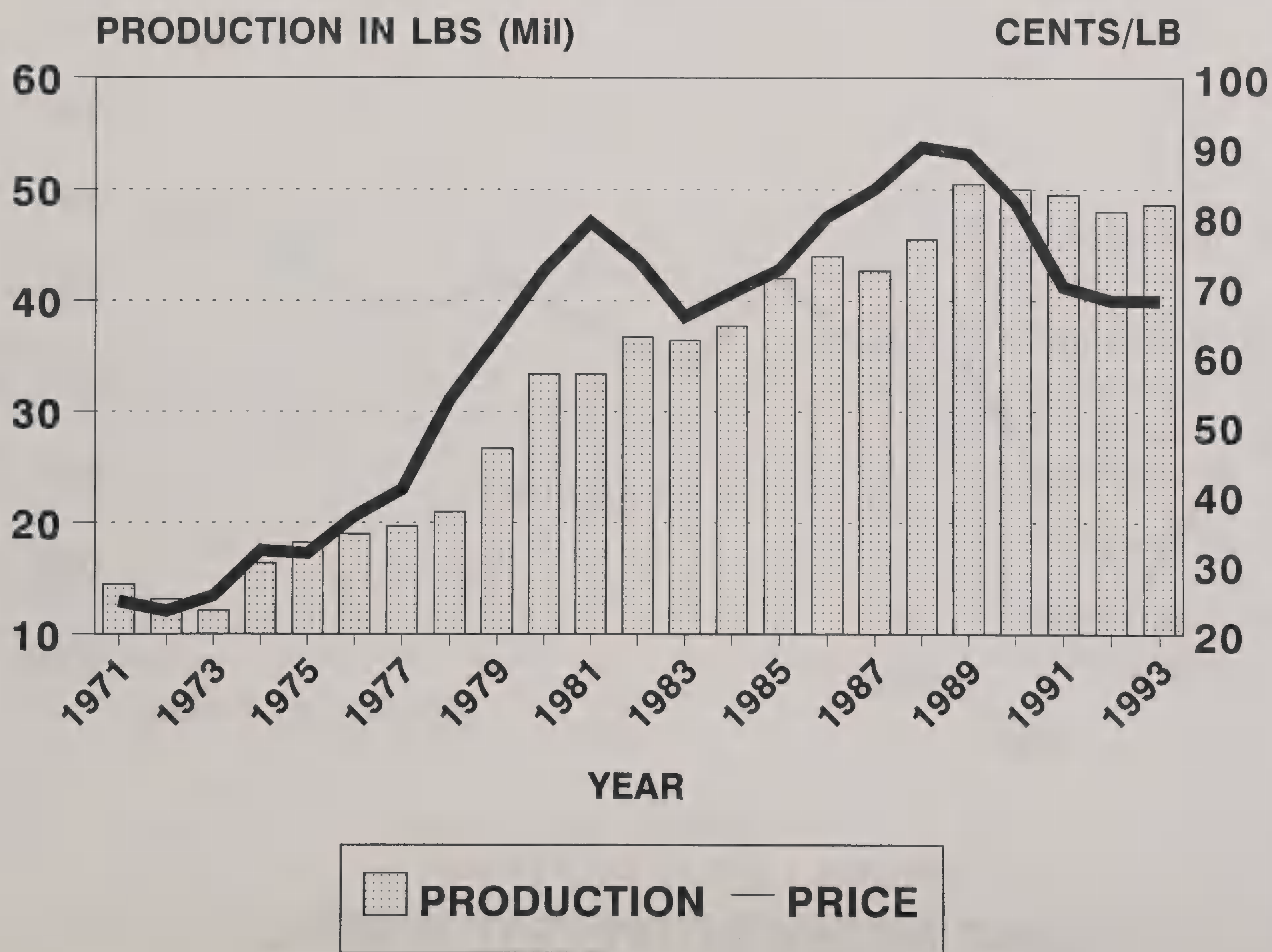


Twelve Yr. Ave. 261,825,000 lbs

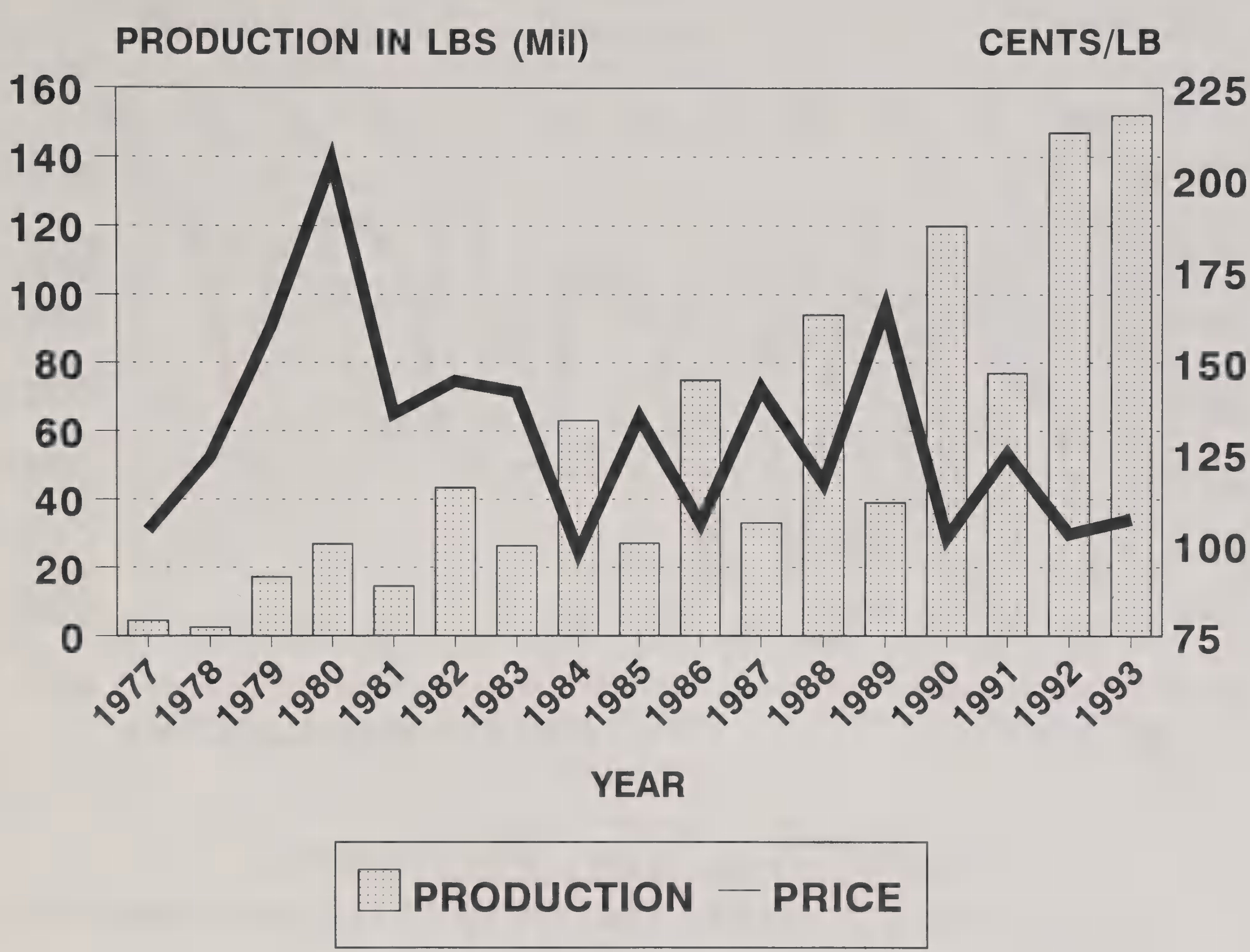
Graph 9. U.S. VALUE PECAN CROP 1980-1993 (Farm Value)



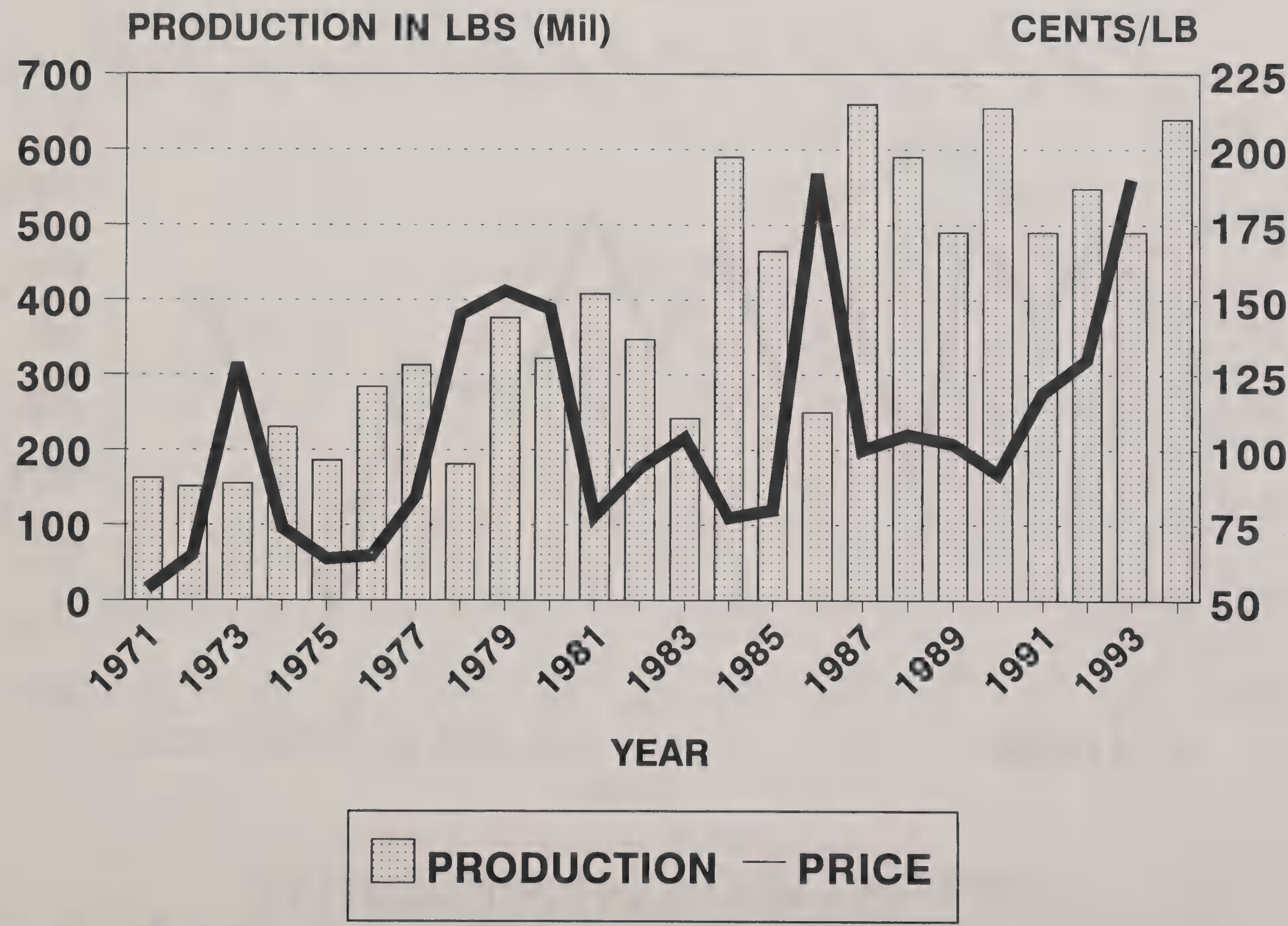
Graph 10. U.S. MACADEMIA PRODUCTION/PRICE HAWAII 1971-1993 (In-shell)



Graph 11. U.S. PISTACHIO PRODUCTION/PRICE CALIFORNIA 1977-1993 (In-shell)

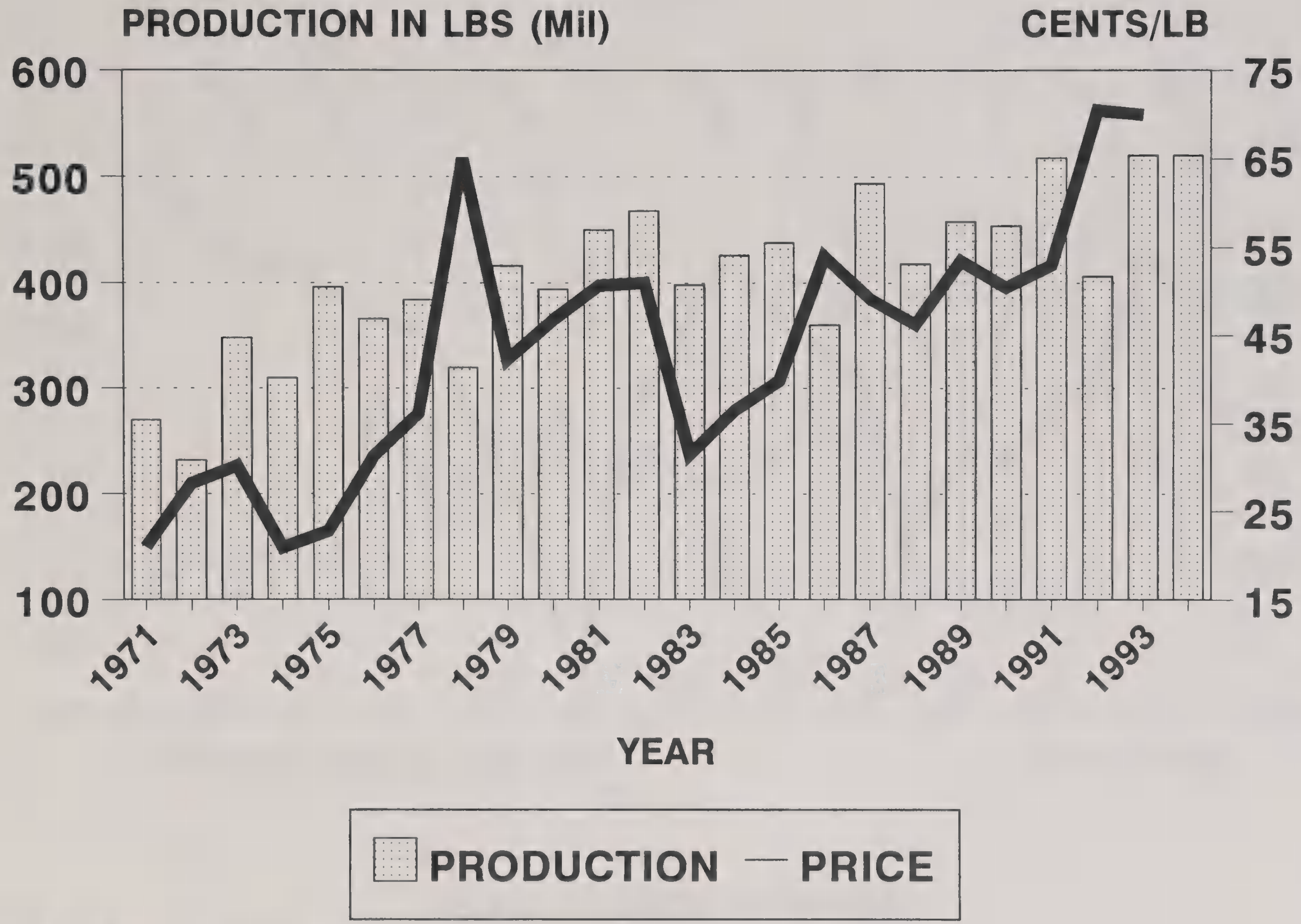


Graph 12. U.S. ALMOND PRODUCTION/PRICE CALIFORNIA 1971-1994 (Shelled)



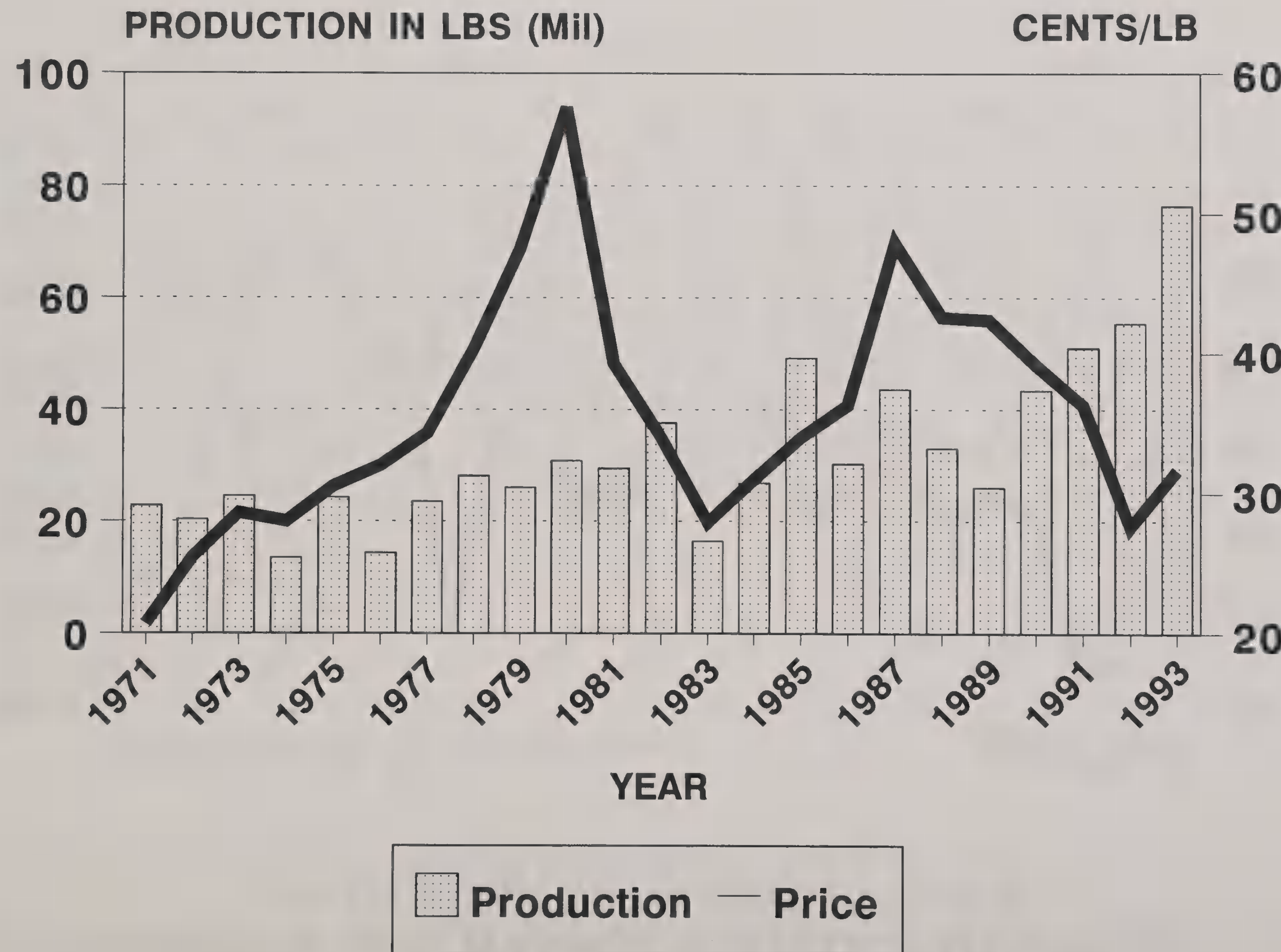
1994 Estimated Forecast

Graph 13. U.S. WALNUT PRODUCTION/PRICE CALIFORNIA 1971-1994 (In-shell)

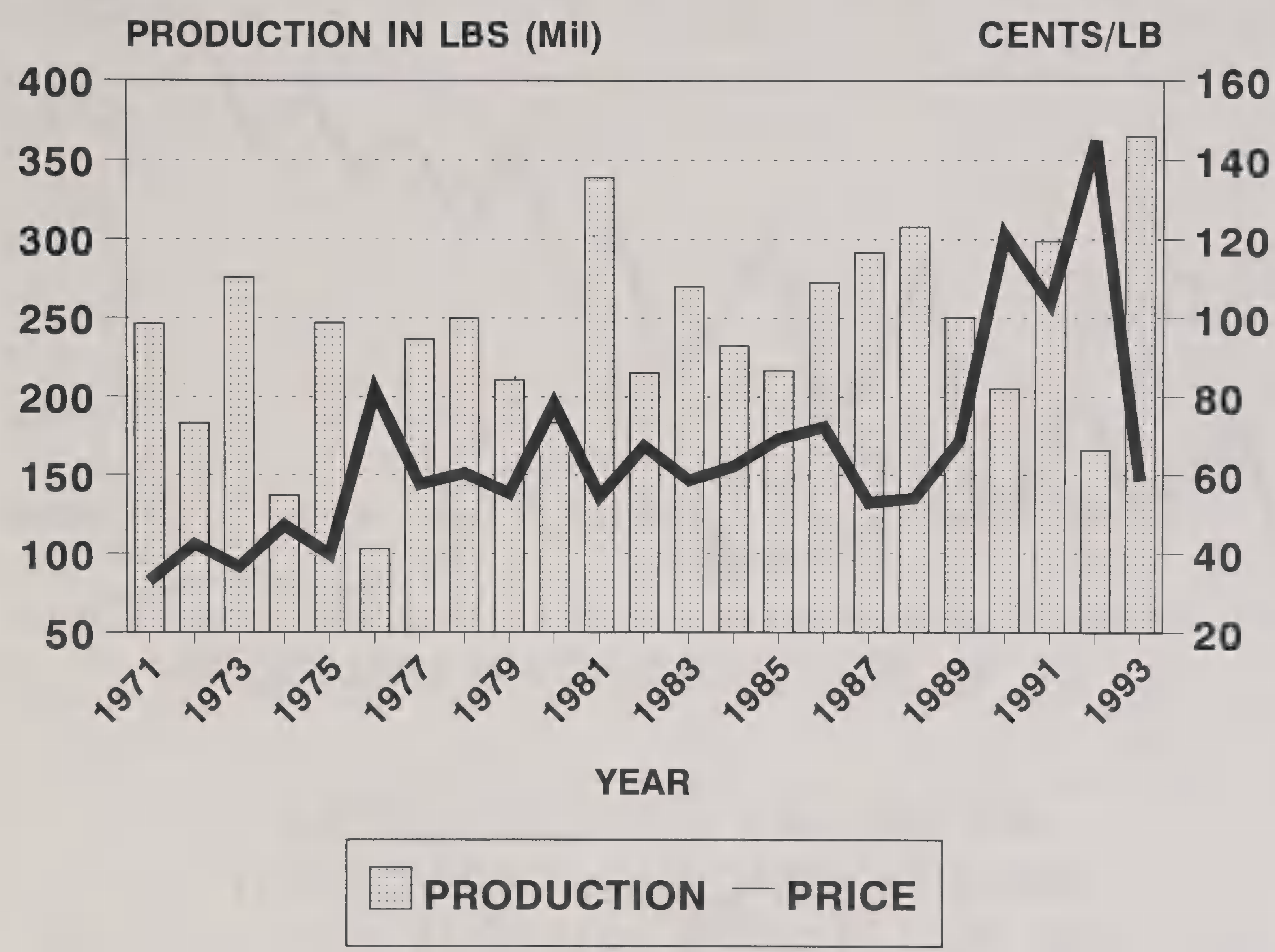


1994 Estimated Forecast

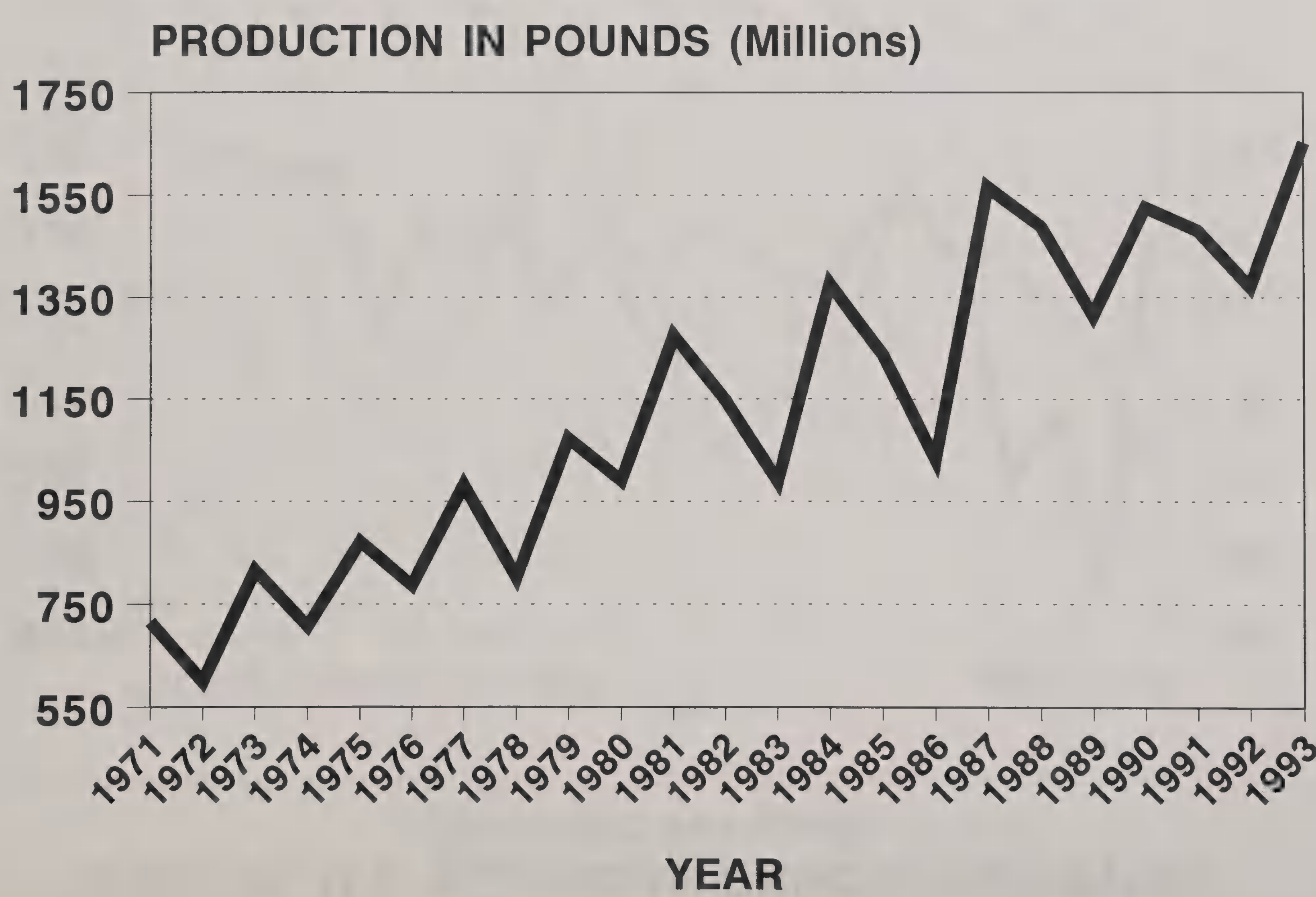
Graph 14. U.S. FILBERT PRODUCTION/PRICE 1971-1993 (In-shell)



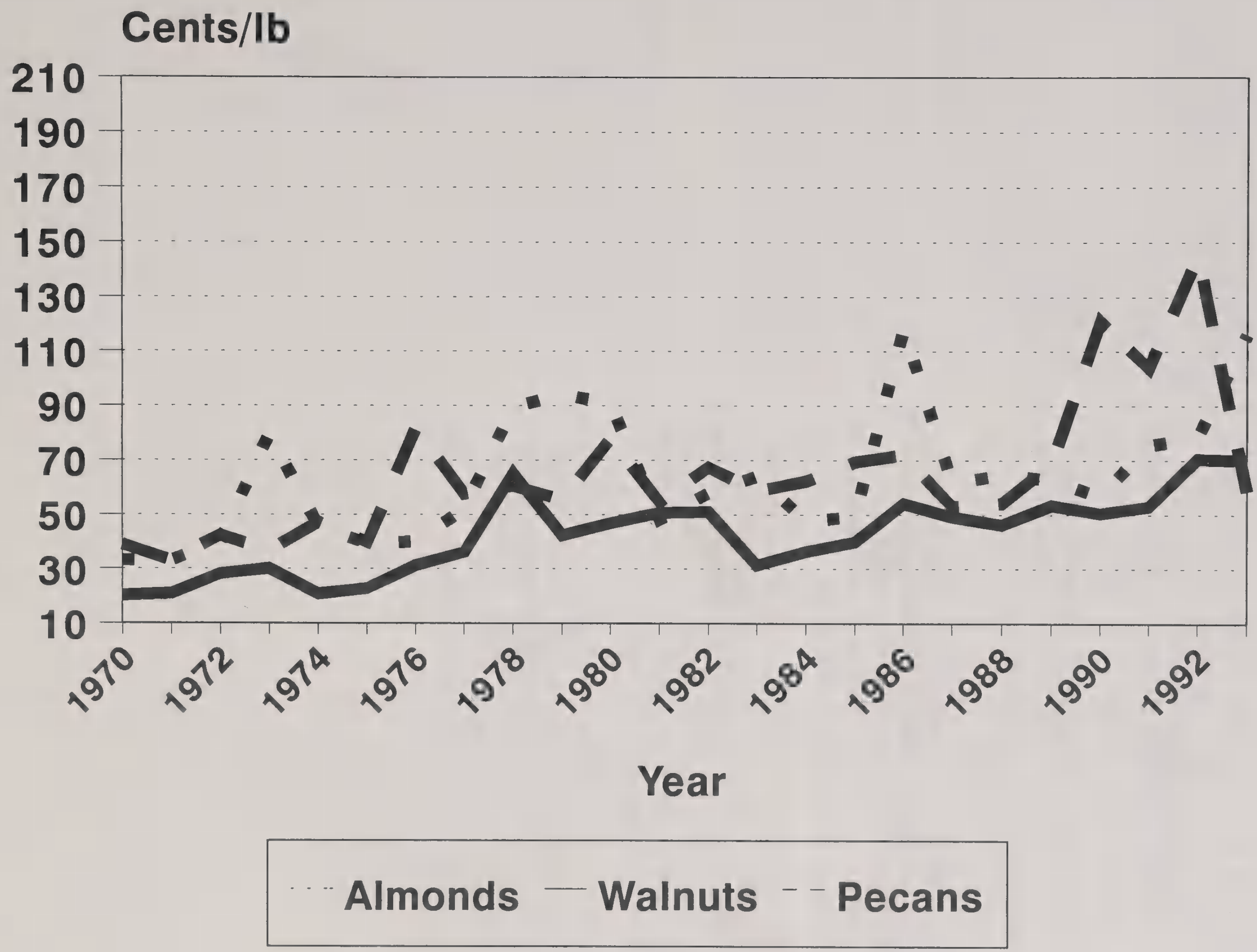
Graph 15. U.S. ALL-PECAN PRODUCTION/PRICE 1971-1993 (In-shell)



Graph 16. U.S. TREE NUT PRODUCTION 1971-1993 MACADAMIA, PISTACHIO, ALMOND FILBERT, WALNUT AND PECAN



Graph 17. AVERAGE PRICES FOR ALMONDS, WALNUTS AND PECANS 1970-1993 (In-Shell Basis)



PECAN PURCHASES VS. INCOME, EDUCATION, AND AGE OF THE UNITED STATES CONSUMERS

E.E. Hubbard, W.J. Florkowski and H. Witt

ABSTRACT

This study presents preliminary results concerning the timing of pecan purchases and the characteristics of consumers purchasing nuts in specific periods. The characteristics selected for this presentation include annual household income, educational attainment level, and age.

The data were collected through a mail survey in 1993. The return rate of the survey was 57.3 percent. This response rate compares favorably to the response rates of other consumer mail surveys.

Results shows that surveyed consumers reported pecan purchases primarily during the Thanksgiving and Christmas/ New Year seasons. However, one-third of the surveyed consumers indicated they purchase pecans regardless of the season, i.e., whenever they needed pecans.

The distribution of respondents among different income categories was relatively even among those reporting purchases during the Christmas/New Year season. Income level seemed to strongly influence pecan purchases during the Thanksgiving season. Respondents with the most years of schooling purchased pecans as needed.

There was little difference in timing pecan purchases during the Thanksgiving and Christmas/New Year periods with regard to respondent age. The differences with regard to age were more pronounced when respondents reported purchases as needed; respondents 55-64 years old and, especially, 65 years old or older increased their purchases regardless of the season.

PERCEPTION OF PECAN TASTE AND THE IMPORTANCE OF PECAN FLAVOR TO THE UNITED STATES CONSUMERS

W.J. Florkowski, E.E. Hubbard and A.H. Elnagheeb

ABSTRACT

This study focused on the importance attached to pecan flavor and the perception of pecan taste in order to increase the effectiveness of targeting pecan promotion. Pecan flavor and taste were related to consumer income, schooling, and age.

The data were collected through a mail survey in 1993. The return rate of the survey was 57.3 percent. Almost all surveyed consumers perceived pecan flavor as important or very important to them. There was an overwhelming emphasis on the importance of flavor across all income, age, and educational attainment levels.

The majority (88 percent) agreed to some extent that pecans taste better than other nuts. However, the opinions about pecans tasting better than other nuts were distributed differently than responses about the importance of flavor. The largest percent of respondents in each income category somewhat agreed that pecans taste better than other nuts; followed by those who agreed with this statement and those who strongly agreed.

The distribution of responses about the superior pecan taste suggested that the largest percentages of respondents in each education category somewhat agreed with the statement while the youngest respondents and the respondents 55 years old to 64 years old were more likely to agree than other age categories that pecans taste better than other nuts.

In general, the perception of pecan taste as superior to other nuts was less pronounced than the importance attached to pecan flavor.

ALTERNATE BEARING AND MACROCLIMATIC RELATIONSHIPS

B.W. Wood[1]

ABSTRACT

The potential for alternate bearing associated problems in pecan is greatly enhanced when trees are stressed. Weather related events, as influenced by climatic factors, are major regulators of alternate bearing in commercial orchards. Climatic characteristics are regulated by macroclimatic factors which have the potential to drastically and radically alter climate and associated weather. Some of these major macroclimatic factors are introduced and briefly discussed regarding their contemporary characteristics. A question is raised pertaining to the vulnerability of the U.S. pecan industry as related to weather related factors. A brief discussion is presented pertaining to how growers, etc. can act to buffer themselves against the economic impact of greater than normal environmental stresses.

INTRODUCTION

An objective of this workshop is to bring to everyones attention information or ideas that can potentially impact on our ability to understand pecan and its entire cropping system, from planting to retailing, so we can aid growers and others associated with the crop to efficiently maximize profits and to provide a quality product to American consumers at a fair price. It is my intent in this communication to present some information about the world in which we live and how certain events could possibly produce a major and dramatic impact on the U.S. pecan industry and its future and on our individual strategies for addressing our goals as mentioned above.

As a long-lived perennial crop, many decisions made today regarding our pecan husbandry strategies will have long-lived ramifications that may not be readily apparent; many of which may not be economically correctable, or if so, then only after considerable economic pain. This long-lived nature subjects pecan growers, and other industry affiliates, to much greater potential vulnerability than those who husband most other crops, especially annual or biennial crops. What facilitates an acceptable level of revenue today may be miserably deficient tomorrow. As key individuals influencing decisions made by the industry and its affiliates we scientists need to not only address current problems but also function as a watchman who scans the horizon for the approach of unexpected problems, especially being on lookout for those of potentially great destructive influence. When we think we see an approaching problem on the horizon we are faced with a decision as to whether we should sound the alarm or just to continue as if all is well but keeping an eye on what may possibly be happening on the horizon. There are potentially great risk associated with either option and this risk is proportional to just how big the perceived or real problem, or approaching storm, might be.

From my perspective, I think I see several such storm clouds on the horizon, a virtual squaw line of dark clouds. Among these are: greatly reduced funding for real-world research on pecan; increasing inability of the industry to effectively function as one entity focused on the common good; loss of most of the more useful chemical weapons currently relied upon to defend against disease, insect, and weed pests; and decline in pecans portion of the share of the market that which is presently possessed by tree-nuts. There is however one storm cloud that appears to be developing on the horizon that could potentially dwarf all others, as does the giant cumulonimbus (which spawns tornadoes) towers over the typical summer afternoon cumulus. This cloud, or potential problem, is that we may possibly be on the threshold of entering an era of greatly increased atmospheric instability or flux; or stated another way, a substantial change in weather characteristics, or perhaps even a change in our climate. While proof for such a short-term change remains elusive, climatologist know that in regards to climate, nothing stays the same. All will change, its just a question of how much and when. They have accumulated data that many of them interpreted to indicate that a short-term change may be much sooner than anyone had previously thought. What does this mean to the U.S. pecan industry? Should pecan growers begin to consider countermeasures so they can be buffered as much as possible against such an event? Should we wait for more information? What can the pecan industry or its individual components do?

The objective of this communication is to point out a possible concern, provide orientation regarding some of the macroclimatic factors which control atmospheric conditions, present some evidence that raiseds ones suspicions that something might already be happening, and to suggests in a general manner some precautions that might be considered by orchard managers/growers if such events transpire. The theme of this discussion is therefore "weather and climate" and whether the pecan industry is exposed to greater risk than it realizes.

BACKGROUND

At the level of the pecan tree, alternate bearing is regulated by physiological processes which are directed by the interaction of environmental and genetic factors. The interaction determines the period and amplitude of the alternate bearing mode. Modes are potentially present at

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several levels, these being: major limb, tree, orchard, and geographical. While alternation patterns for individual trees are typically biennial, patterns are also present within states and at the national level . For example, production cycles in the U.S. as a whole exists with periods of 2 years for cultivar nuts and both 2 and 9 years for seedling nuts. Production in Georgia cycles on 3 (Cultivar) and 13 (Seedling) year cycles, whereas that in Texas is on a 5 and 9 year cycle for cultivars and a 2 and 9 year cycle for seedlings. Such cycles and epicycles can arguably be attributable to a variety of factors however extreme weather events are likely the salient candidate because of their profound influence on major stress factors such as water, temperature, sunlight, and pests.

Pecan growers, and the trees they husband, are essentially "bottom dwellers" in an rather shallow ocean of gases and are therefore subject to the direct and indirect influences of this ocean on fundamental environmental properties such as the timing and magnitude of temperature, light, precipitation, and wind. Such factors, of course, act and interact to bless or curse the fortunes of this oceans inhabitants. Its circulation patterns are fortunately rather stable and largely predictable over a period of a few days but somewhat unpredictable over months or years; although, the general characteristics of the annual cycles are presently highly predictable. This long-term predictability has obviously allowed us "bottom dwellers" to confidently establish our orchards in geographical locals where the trees we husband are satisfactorily adapted to the physical characteristics of that particular locations gaseous environment. Under such conditions, nut yields and revenues are secured and we prosper if were smart and/or lucky. Prosperity is not just dependent upon wise judgement in the selection and execution of cultural and management strategies but also on atmospheric stability. Increased instability in this gaseous system can easily increase the stresses to which our trees are exposed and disrupt revenues via alternate bearing and a multitude of other means.

MACROCLIMATIC FORCES

There are several macroclimatic forces that control atmospheric stability. Five of these are briefly discussed as follows:

Solar irradiation. Energy received from our sun is the primary driving force of our climate and weather. Relatively small changes in the receipt and retention of solar irradiation can produce major changes in atmospheric characteristics. Due to the spherical nature of our planet intercepted sunlight results in the tropical or more equatorial portions receiving more energy than that of extratropical regions. This imbalance and subsequent energy gradient drives atmospheric and oceanic movement. There is also unequal heating within tropical regions. Heating is greatest where atmospheric convection is greatest. These are in the Amazon Basin, equatorial Africa, and Indonesian archipelago. These three regions of extra strong heating are terrestrial fire-boxes that energize circulation of both atmosphere and oceans. Any factor which influences either tropical or extratropical heating therefore influences circulation which in turn alters weather and potentially climate.

Of potentially several candidates, two in particular are thought to exhibit an inordinate threat to the atmospheric systems stability. These are the suns stability and the disappearance of forest within these "fire-boxes". Peculiar oscillations have recently been observed in the sun. This is a concern since the fusion processes bathing earth with radiant energy is in a state of flux . The dynamics of this fusion process causes increases in magnetic storms on the sun and subsequently appears to influence earths temperature and subsequently weather. These storms or spots have a mean period of 11 years but can vary greatly. Similarly, deforestation within the local fire-boxes threatens to alter the transfer of energy within the atmosphere and therefore will influence weather.

Polar Jet Stream. The atmospheric hemispheres are encircled by a narrow current of fast moving air which meanders around the globe, oscillating from North to South. This current, or river, is about 300 miles wide and nearly two miles deep. Wind speeds typically vary between 100 and 300 miles per hour. It exercises two key roles. First, it guides low pressure systems, or storms, around the hemispheres; therefore, exercising major control over when and how storms will occur and tract. Second, it serves as a boundary between warm and cool air, thus controlling surface temperatures and the formation of storm systems.

Bermuda High. This is a large mass of warm moist tropical air which moves westward from the Caribbean to the western Gulf of Mexico and then to the eastern half of the U.S. It oscillates from North to South and a primary regulator of weather in the eastern U.S.
The Bermuda High and the Polar Jet are usually far apart. When they get close together a lot of rain is produced along the ascending portion of the Polar Jet and dry weather in produced to the southeast of this zone.

Greenhouse Gases and Dust. Entry of certain gases, such as carbon dioxide, sulfur dioxide, methane, etc. into the atmosphere interfere with the escape of radiation from the earths surface, creating a Greenhouse Effect in which less energy is lost and the atmosphere is heated. Industrialization has contributed substantial levels of such gases to the atmosphere and therefore potentially affects weather. Volcanism is also a major source of such gases and it also contributed great amounts of dust to the atmosphere which increases reflectance and thus alters the energy balance of the atmosphere.

Southern Oscillation/El Nino. The Southern Oscillation is a standing wave, "see-saw", in atmospheric mass involving exchanges of air between Eastern and Western Hemispheres with centers of action over Indonesia and tropical South Pacific Ocean. When air pressure is great in one area it is proportionally less in the other. This standing wave influences atmospheric circulation patterns. One process by which it does so is via 'teleconnections'. An alteration in the characteristics of an atmospheric wave in on portion of the wave train results in alterations downstream. For example, oscillations in the Southern Oscillation can influence the Polar Jets which in turn influence storm systems and the latitudinal movement of air masses thus local weather characteristics are influenced. This principle of teleconnection provides a linkages over great distances of seemingly disconnected weather anomalies. Other "Oscillations", such as the "North Pacific Oscillation" and the "North Atlantic Oscillation" are therefore linked to each other by "teleconnections" and the "Southern Oscillation" is thought to be the most powerful anomaly of the any of the various "Oscillations". The Southern Oscillation is intimately associated with certain cold/warm water currents in the eastern Pacific Ocean. Strong oscillations in this anomaly result in the formation of Pacific Ocean currents which also alter weather systems. These two phases are termed "La Nina" and "El Nino". Weather events on many portions of the globe exhibit close associations with these "El Nino-Southern Oscillation" phases. This phase results in an invasion of warm water from the western equatorial Pacific into the eastern equatorial Pacific Ocean resulting in a warming of the tropical Pacific region. This can results in abnormally wet weather in the southern U. S. pecan belt, flooding in the South, with severe storms in the southwest. Similar weather is experienced in western Ecuador and Peru and the United Kingdom. Excessively dry weather i s experienced in equatorial Africa, eastern Brazil, northern China, eastern Australia, and Indonesian archipelago. Also, warm winters are encountered in the northern U.S. and western Europe with exceptionally cold in Siberia and Greenland.

The frequency of "low" and "high" magnitude "El Nino-Southern Oscillation" events have generally increased over the last 400 years. The frequency of severe events within the last 43 years has been 3-4 fold than that of 50 year intervals back to 1600 A.D. This increase in frequency of severe events is taken as evidence that atmospheric circulation is entering a state of atypical flux, at least in regards to historical times. The correlations of weather conditions in certain portions of the world with the presence of the El Nino, indicates the potential for predicting weather conditions several months in advance for certain areas of the world. These events exhibit low frequency and are quasiperiodic with events occurring every 3-4 years. Thus the probability greatly increases that an 'El Nino- Southern Oscillation' event will occur once 3-4 years has elapsed since the last event.

EVIDENCE FOR CONCERN

Over the last few decades the quality of Japanese products has steadily increased to the point that many of them are generally recognized as being in the world. Much of the credit to this economic miracle goes to the principles of quality control taught to them by Dr. E. Demming from the U.S. He had some very definite opinions about how products should be manufactured is companies were to remain competitive; however, hardly any U.S. company was willing to listen to his ideas. His concepts met a highly receptive audience in the Japanese. One principal that he advocated was the need to continuously monitor the variation associated in the manufacture of components and products, thus leading to methods that allowed manufacturers to determine when something was about to break. There is variability in all systems and this variability substantially increases as something begins to break or wear out. By monitoring this variability and the magnitude and frequency of events, one is able to become alerted to a problem before it becomes obvious. The following is a brief description of several events which either are exhibiting more variation than is typical or otherwise provides evidence of unexpected climatic changes.

A) Ice Core Project: This international project studies ice core from glaciers throughout the world, especially in Greenland, Chile, and the Antarctic. Scientists working with these cores have recently been astonished to find that the earth is capable of dramatic climate changes in one to three years. These findings also indicate that these changes were essentially worldwide. Some of these researchers conclude that "we're living in a world that has switches, and we don't know what they are. Flip a switch, and we get big climate changes. We humans are stumbling in the dark and might flip one of these switches". The last 10,000 years of climate has been remarkably stable, however based on the story preserved in over 250,000 years of layer upon layer of ice, there is substantial evidence that the climate of Greenland in particular and probably the earth in general has switched 35 times during this period of time and we are 8,000 years overdue for the next switching. "The earth's system is capable of jumping from one climate to another, and it's something we have to worry about. The message I get from this is, don't stick pins in the climate's tail. It's an ornery beast. Ice cores showed that very rapid changes occurred. The earth is screaming at us, "I can do it! I've done it before and I can do it again". The change is on the order of changing the climate of Duluth, MN, to that of Atlanta, GA, or vice versa, with little or no warning. These switches may include greenhouse gases such as carbon dioxide and methane, causing the Earth to warm, dust in the atmosphere which blocks sunlight, causing the Earth to cool, and other variables such as melting ice sheets and shifting ocean or atmospheric currents. Gases and/or dust ejected into the atmosphere from volcanic activity, especially when ejected into the upper atmosphere, are also likely candidates as triggers of these switches.

B) "Southern Oscillation" Events: As eluded to earlier, there has been a major increase in the frequency of "SO" events in the South Pacific since about 1600. This increase has been especially pronounced during the last 40 years. These events can lead to a proportional increase in the frequency of El Nino and La Nina events.

C) "La Nina and El Nino" Events: These event influence greatly weather patterns around the world, resulting in excessive rainfall or drought and abnormal temperatures. The frequency of these events have substantially increased in recent years with an exceptionally high frequency occurring within the last 10 years.

D) Increased Mean Atmospheric Temperature: The mean atmospheric temperature of both the Northern and the Southern Atmosphere has increased over the last 80 years, with the increase being especially noticeable in the Southern Hemisphere, which is where the bulk of the air mass is situated that is directly associated with the Southern Oscillation events.

E) Increased Concentration of Greenhouse Gases: The mean global concentration of carbon dioxide in particular has steadily increased from about 280 ppm to 380 ppm during the last 100 years. This rate of increase is accelerating and will continue to do so as long as fossil fuels continue to be oxidized.

F) Increased Frequency and Severity of Hurricanes and Typhoons: The frequency and strength of these storms are related to the energy gradients frond in the atmospheric ocean and between Earth's aqueous and gaseous oceans. The greater this gradient, the more and the stronger these storms will be. While it is not yet clear that this has happened, there is strong circumstantial evidence that this is about to become the case.

G) Increased Ejection of Volcanic Gases and Dusts: While there does not appear to be clear evidence that volcanic activity on the Earth is generally any different that it has been for many thousands of years, it is clear that the Earth is overdue for some of the really big volcanic eruptions that are typical at the historic level. Eruptions on the order of that of Tambura and others within the East Indies have not occurred within the lasts 100 years and are probably overdue. Eruptions 100-500 times more massive than that of Mt. St. Helens are not uncommon prior to a century ago and such eruptions today could possibly function as the finger that flips the switch which causes a shift in Earth's climatic characteristics.

H) Increased Frequency of Weather Anomalies: One thing for sure about the weather in most of the U.S. is that it can be depended upon to change; this is especially true in the Temperate Zone of our country. It is difficult to conclude from weather events that thing are changing and is therefore a very risky enterprise. However, based on precipitation records from the Georgia Pecan Belt from 1930-1991 precipitation anomalies have greatly increased beginning in 1989. This effect has been especially noticeable this July with the 500 year flood in Georgia. However, even without this recent flood, the frequency and severity of wet and dry periods in Georgia have been especially anomalous, perhaps being the major causal factor influencing the loss of nut yields in Georgia over the last 5 years.

There are a multitude of other weather events within the U.S. over the last few years (ex. November freeze, droughts in the southeast, floods and rain in the southwest, wet seasons, dry seasons, hurricane frequency, freak blizzards, etc.) which collectively exhibit substantial evidence for being more than just the normal variation in annual weather. The severity of the event combined with the short time table in which their occurrence has been compressed brings to mind the concept of variability as espoused by Dr. Demming. Things appear to be much more variable than in the decades prior to the last, and the frequency of these deviations appear to be much greater. This may be evidence that Mother Nature may be doing something she has done many times before, but we just weren't around to write about it. Could it be that Mother Nature is trying to tell us something? Could it be that the "climatic switch" has already been flipped and we are now only beginning to view the weather related changes associated with the transition from one climatic epoch to another? Or, is there still time to protect the switch or to reverse it if it has indeed been flipped? If it has already been flipped or is going to be flipped within a few years, how can the U.S. pecan industry prepare so as to minimize its impact?

PRECAUTIONS

It is anybodies guess whether the above described climatic shift is already taking place or will hold off for another million or so years. Until it becomes obvious that it is happening precautionary efforts may simply be a waste of time and perhaps money. But with an especially long-lived crop such as pecan , we pecan people have good reason to keep our eyes focused a good bit further across the horizon than do most folks.

What could we expect during the transitionary phases of such a change and what would pecan growing be like if it were to occur? Well, again it's anybodies guess. It is however probably safe to say that there will be both quantitative and qualitative abnormalities in factors relating to water, temperature, and wind. Rainfall and temperature characteristics can potentially cause problems with factors such as disease and insect populations, cold damage, hail and wind damage, vivipary, harvesting, nut quality, etc. In summary, one could say that it would be difficult to obtain stable production of reasonable quality nuts; this being similar to that which has been experienced in the southeastern U.S. since 1989. Abnormal weather events

will lead to higher levels of physiological stress to our trees. And as you know, pecan trees are hypersensitive to biotic and abiotic stresses, resulting in all of the problems associated with severe alternate bearing; therefore, alternate bearing would become much more severe of a problem than it is at present.

So what can be done to cope with these potential stress inducing factors? It appears to me that growers would be wise to buffer themselves from these potentially higher levels of stress by giving some serious thought to their cropping strategies, all with the ideal of minimizing tree stress. There are a several things that they could do.

These strategies should focus on addressing 'fixed' (those factors which can not easily be altered) factors that are associated with their orchard operations. This includes things such as tree spacing for increasing sunlight availability; establishment of cultivars which do not overcrop or can be fruit thinned if they do; cultivars that have the greatest resistance to the major pest such as scab, glomerella, leaf scorch, and black aphids; choice of cultivars which have proven to be most resistant to stress factors; use of cultivars with thick or naturally plump kernels and are of medium size or smaller (avoidance of large nut types, especially when they set more than 2 nuts per cluster); use of the most appropriate rootstock for the soils being cropped; and avoidance of cultivation of pecan or its particular cultivars near areas where the environmental conditions (such as length of growing season, cold hours, fall freezes, soil types, rainfall, etc.) are already marginal; planting four cultivars instead of the usual two so as to minimize the likelihood for losses associated with noncomplementary overlap of flowering due to abnormal chilling conditions; having plantings consisting of relative young trees rather than the more easily stressed older trees; establishing orchards in regions where pecan pests are already minimal; and avoidance of planting on sites where there is a high probability of exposure to hurricanes, tornadoes, or strong winds. Some 'nonfixed' factors that need to be seriously considered are factors such as optimumal nutritional management, optimum availability of water via irrigation, and techniques for fruit thinning; equipment being readily available for meeting the needs for the control of disease and insect pests; expertise in ecosystem management of pecan orchards; and avoidance of unnecessary debt. These buffeting factors are not all inclusive but should give a clear idea of just what growers might need to do to hedge their investments in pecan cultivation.

SUMMARY

As with any change in the environment, be it sudden or gradual, there is going to be pressure to change or to become extinct. It is my impression that there are a lot of pecan growers and affiliated folks that are already facing the prospects of extinction because of the stresses to which they have already been exposed. How much more stress is required before there is to be a major change in the nature of the industry? This is especially true for many growers in the southeastern U.S. as a result of crop losses linked to weather anomalies experienced from 1989 until the present. The pecan industry is undergoing evolutionary-like change and appears to be on the brink of being required to make drastic adaptations or many of its entities are destined to meet a fate similar to that of the dinosaur. Times of rapid environmental change and stresses is also a time of great opportunity to those who can rapidly adapt. I suspect that there is a very good chance that the future will afford conservative, moderately lucky, and horizon wary pecan folks a growth opportunity never before available since it is nature's law that the losses of one becomes the gain of another.

Well, this communication contains a lot of speculation and may possibly be of little or no significance; however, it addresses apparent facts and trends that may just possibly be of great importance, perhaps more than we can imagine. There seems to be just too much evidence to continue as if there was no cause for concern about the potential weather related problems that may be looming on the horizon. Only time will tell. It is hoped this brief accounting of observations and presentation of ideas has accomplished my objective of causing you to pause, look about, and think.

EARLY PECAN HARVEST

T.G. Stevenson[1]

Good morning Ladies and Gentlemen. My name is Tom Stevenson. I reside in Albany, Georgia and am involved in the ownership and/or management of six pecan orchards totaling 2100 acres. Approximately 350 of these acres are in the Winter Garden area of south Texas, 40 miles east of Eagle Pass, with the balance in the Albany area. I was born in the San Joaquin valley of California but grew up in the Santa Cruz valley of southern Arizona, between Tucson and Nogales. In the fifties this valley produced cattle, cotton and small grains but even at this early time there was experimenting with pecan production through trial plantings. My first exposure to commercial pecan production came when FICO decided to plant the orchards which are now in production. This was in 1965, nearly 30 years ago. Since then I have had the opportunity to be involved in pecan production in Texas, Florida and Georgia, encompassing most of the U.S. pecan belt. It has been both rewarding and frustrating but always a challenge. As I stand here today and ponder all of the accumulated university degrees, doctorates and hours of research I marvel at how much we still do not know about the crop we are growing. I suppose, for me at least, that is what makes agriculture so interesting.

I have been asked to talk to you today about the advantages and disadvantages of early nut harvest. I do not know exactly what I am supposed to tell you but I will try to relate my experiences with it and what I perceive to be the advantages and disadvantages. My definition of early harvest is at that time when the nut is physiologically mature and will not lose any weight or meat yield during the drying process. From our experience we find that this occurs when the shell markings are virtually complete and have turned in color from reddish to dark brown or black. The vascular bundle may still be attached to the shuck but will be dry or drying and the butt of the nut will have little or no white on it. It is better to be a day or two late on this as trials at our farm in Texas have indicated that for every day you are too early you will lose one quarter to one half per cent in meat yield during the drying period, which may be as long as four days at this moisture level. Over four days this could result in a two per cent meat loss. We proceed when ninety to ninety five per cent of the nuts sampled reach the maturity described above. This is determined by a random sample taken every other day from the orchard, starting about 2 weeks prior to expected maturity. I will begin by discussing the disadvantages of an early harvest. First of all the decision to harvest early automatically forces you to make two harvests since you will not get all of the crop this first harvest. Depending on tree size, variety and shaking capability you will get somewhere between forty five and sixty five per cent of the crop the first pass. You have committed yourself to two harvests and though the second harvest will represent fifty per cent or less of your crop production it will cost just as much on a per acre basis as the first harvest and probably more on a per pound basis. Depending somewhat on your circumstances we figure direct harvest costs to run about thirty to thirty five dollars per acre per harvest. This is a total of seventy dollars per acre for the season. On a total yield of fifteen hundred pounds per acre this is about five cents per pound in shell, or seven cents per pound on a thousand pound yield. Your entire harvest season will just about double and depending on your lifestyle and other commitments you may not want or be able to devote this amount of time to harvest. My harvest season starts in Texas about the 20th of September and ends four months later about the 20th of January in Georgia. You may wish to modify this and only harvest certain varieties early while not doing those that have no market advantage. Be cautious of shaking young trees this early in the year. It is easy to slip the bark and damage them.

Once into the cleaning plant your costs will be higher with early harvest since a high percentage of the nuts will have to be de-hulled. There will be some loss due to crackage in the hullers and other grading steps, as well as some immature nuts that will be discarded during grading. Higher costs will also come with increased utility costs as drying times are longer and more energy is used. Drying is the most important thing that goes on that this time and can hurt your quality and ultimate meat yield if not done properly. Dryer air should be no hotter than 90 degrees F, which usually is ambient temperature in Texas at that time of year. Dryers with automatic thermostats will usually only fire in the night after temperatures have dropped and the relative humidity has risen. I cannot over emphasize the damage that can be done with hot air dryers if it is not done properly. We do not even turn the burners on the 1st 24 to 36 hours so the that meat and shell moisture has a chance to equalize somewhat. Pay close attention to cleaning and drying operations. Your labor usage will be extended over a greater period of time and can run up your costs if not managed properly. Total cleaning plant costs which include labor, labor overhead, utilities and propane, insurance, bags and supplies, repairs and depreciation are calculated at twelve cents per pound for an average crop but this will fluctuate with crop size as some of your costs are fixed and will raise your cost per pound when a small volume is processed. Depending on the volume and quality of your crop you should have it mechanically harvested, cleaned, graded, bagged and loaded on a truck at your farm for under twenty cents per pound. The higher the volume and the better the quality the lower your costs will be.

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[1] Albany, GA

The primary two reasons to harvest early are to take advantage of higher early season prices and to reduce your exposure to weather and varmints. We do it because we know the increased value of the nut early in the season is more than enough to justify the extra expense of the double harvest. We also end up with higher total yields since less of the nuts are left out for varmints and bad weather. Color is lighter early, enhancing value and in Texas we have less exposure to sprouting problems with Wichita, though all varieties I have seen in the area will sprout under the right conditions. We also find less nut loss behind the harvest crews after two trips as opposed to one harvest. The first pass is quick to get the early prices and the second pass is more oriented toward a good harvest job so that as little as possible is left behind. This extra chance combined with the other factors mentioned all help to raise our total yields. There is usually three weeks between the first and second harvest. In Georgia there are years when we have to wait after the first harvest for a killing freeze before proceeding with the second harvest. In Texas this does not occur until January normally and there we proceed without the benefit of a freeze. At times a third pass there can be justified.

The highest price for good quality nuts is almost always at its peak early in the season. The gift packer is the dominant force in this early market as they must have new crop nuts for their product and they must process it early enough so that it can get back out to their customers in time for the holiday season. Mid to late November is about as late as they can take in raw nuts and still get the product processed and back out for the last of the holiday season. In almost all years you will see a drop in cash prices paid to growers at about this time. The gift pack people pull back and let the commercial shellers in, which usually drops the price. The gift packers may still be players in this market but are content to buy at levels established by others that are generally lower than the pre- Thanksgiving prices. This price difference in south Texas vs. December in south Georgia may be as much as 60 cents per pound. Even in Georgia, those quality nuts delivered prior to this time are worth 15 to 20 cents more per pound. By early December it is a commercial sheller's market and the prices reflect this. The gift pack trade is a limited one of 12 to 14 million pounds and could be saturated if enough plantings in early maturing locations were established and well managed. To be successful in this market you must be quality oriented and be able to get the product to the buyer in a timely manner. Gift packers usually pay the top of the market, but expect the cream of the crop in terms of quality. You can also expect them to be repeat customers if you establish a reputation for quality and reliable delivery.

PECAN NUTRITION

R.E. Worley[1]

INTRODUCTION

Pecan nutrition is a very broad topic, certainly too broad to be covered in detail here. I will try to hit the high spots on the topic and document the references so that the reader can do further reading if desired. Since this is a review, the measurement system presented in the original manuscripts will be used when discussed in this manuscript. Several reviews of pecan nutrition have already been published (O'Barr 1977, Sparks 1989a, Smith 1991a).

Pecan is a crop that has recently literally come out of the woods with many native trees still in the woods. Pecan research in general and pecan nutrition research in particular is of recent origin relative to most other crops. Some of the earliest work on pecan nutrition was conducted by J.J. Skinner (Fowler et al. 1933, Skinner 1921, 1922, 1923, 1927, Skinner and Rupreht 1926). His early experiments used the triangular method of arranging treatment combinations of NH_3, P_2O_5 and K_2O. The treatments were arranged so the percentage of the three nutrients totaled 20% with nutrient levels of each varying from 0, 4, 8, 12, 16, and 20% in all combinations. This was before statistical designs were developed, but he unknowingly was using a complete factorial arrangement of treatments. Replication and randomization were probably lacking.

These studies and others (Anon. 1966, Anon 1975, Blackmon 1936, 1937, Lewis and Fowler 1936, Ware and Johnson 1958, Hunter and Hammar 1961, Koen et al. 1978, McHatton 1924, Taylor 1930) usually indicated that N was the most important nutrient, but the trees usually grew better when all three nutrients were included.

Later studies indicated that pecan trees may be slow to respond to fertilizer applications if the orchard is in good condition and liberal applications were previously made (Gammon and Sharpe 1959, Worley and Harmon 1964, Alben and Hammar 1964, Sullivan 1974, Worley 1991a). Soil and leaf analysis were seldom correlated with yield in a study in such orchards (Worley et al. 1972a).

In one early study, trees fertilized with 1000 lbs/acre of a complete fertilizer for ten years produced equally as well the next ten years without fertilizer (Hunter 1956) indicating the nutritional needs of the tree may not need frequent replenishment. Hunter (1956), and later Sparks (1975a, 1975b, 1978b), indicated that a 1000 lb crop of pecans removes only about 11 lbs of N, 4 lbs of P_2O_5 and 4 lbs of K_2O. An additional 4, 2, and 18 lbs respectively of the three nutrients are returned to the orchard floor in the shucks to be recycled along with that in the fallen leaves. Growers have usually applied much more than this, leaving the soil with abundant P and K. Nitrogen usually being in a soluble form in the sandy soils, is easily leached; however, the organic fraction may hold N and slowly release it back to the tree roots to be recycled.

Recycling nutrients through leaves as they fall, decay, and release the nutrients back to the soil to be reabsorbed by the tree is one of the reasons fertilizer depletion is slow (Sanchez et al. 1991). In the forest (pecan can be considered a forest tree) litterfall is the major pathway for the return of N, P, Ca, and usually Mg to the soil. Nutrient turnover, particularly N turnover, was related to the rate of organic matter turnover. About 80% of the cycle of N from plant to soil is in litter. Turnover time in non-woody litter ranged from 1.4 to more than five years (Adams and Attiwill 1986a, 1986b).

General recommendations are for a complete fertilizer, but research indicates only moderate amounts are needed. Hunter (1960) concluded that optimum rates of fertilization are 50-70, 50-60, and 50-60 lbs/acre of N, P_2O_5 and K_2O respectively, and pointed out that moisture deficiency frequently limits fertilizer responses. Frequently, fertility tests did not reveal responses to fertilizer applications (Hunter and Hammar 1961). Most states now offer leaf and soil testing so growers can apply nutrients by prescription thus omitting application of those not needed.

NITROGEN

Of the nutrients needed by pecan trees, nitrogen is usually the one most frequently needed and applied in largest amounts. Nitrogen deficiency is described as a reduction in growth of all plant parts and a yellowing of the leaves. On one-year-old seedling pecan trees grown in sand culture, the following ranges were developed: 1.8-2.2%—visible N deficiency symptoms, 2.2-2.6%—region of hidden deficiency; no visible leaf symptoms but trees continued to grow as N level was increased, 2.6-2.9%—region of optimum growth, 2.9% and above—region of excessive N. Similar ranges were obtained for seven-year-old 'Desirable' trees at Waycross, Ga. (Sparks 1968).

Usually 50 to 100 lbs N/acre (Worley 1991a, Smith et al. 1985, Young and Bryan 1966) supply the trees' annual needs. Many early trials indicated responses in yield and/or growth from its application (Lewis and Hunter 1944, Hunter 1964). Nitrogen fertilized trees had greener foliage, initiated earlier spring growth and had higher yields, but nut percentage kernel and oil concentration were reduced compared with unfertilized trees (Hunter 1964). In our

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Tifton studies high N rates increased fruit set and reduced nut size. The best compromise between yield, nut size and kernel quality was to apply 100 lbs/acre N when Leaf N in July was <2.75% (Worley 1990a). Greenhouse nutrient culture of seedlings indicated the best growth at leaf concentrations of 2.7-2.9% (Sparks and Baker 1975). In Oklahoma (Smith et al. 1985) the highest yields were from the first 56 kg/ha increment of N. Similar results were obtained in Texas. The only detectable yield reduction was found in unfertilized trees on sandy soils where tissue N level was below 2% (Malstrom et al. 1983). In our studies at Waycross, yield increased with increasing N application to 112 kg/ha, but differences were not significantly better at 112 Kg/ha than that for 56 kg/ha (Worley 1974). Leaf nitrogen concentrations are generally lower in Oklahoma than in most other states when fertilized similarly. High N application is not only an unnecessary expense, but it can reduce quality and nut size (Sullivan 1974). A N rate of 436 kg/ha reduced yield by 80%, doubled the number of sticktights and reduced nut size (Storey et al. 1986). Sparks (1986b) concluded that trees that produce too many nuts should receive less N to reduce the fruit load and suggests a leaf concentration of 2.4-2.6%.

PHOSPHORUS

Phosphorus usually has been abundantly supplied to most pecan orchards and since it is immobile in the soil and little has been removed by the crop, most of it is still there. Phosphorus was being accumulated in soils with the lowest application rate of 0.1 lb P_2O_5/inch of circumference in Waycross studies (Worley and Harmon 1964). Responses to additions of phosphorus in the field have been extremely rare. Phosphorus in leaves varied greatly with soil type, cultivar and year. Some soils (Yahola loam, Miller clay and Oawchita loam) have abundant P. Others (Lintonia silt) were low in P in the topsoil but higher in lower layers. None of the soils had a yield response to added P (Alben and Hammar 1939). Sullivan (1974) obtained no yield or quality responses from applications from 0-200 lbs P_2O_5/ acre. In Waycross, Ga. tests, we did not obtain yield or quality responses from P additions (Worley 1974). In Oklahoma, the addition of 244 kg P/ha twice in a 5-year period increased leaf P in three years but had no effect on the number of new shoots, nut quality or nut yield (Smith 1991b). Sparks (1988) increased nut volume by 1 cc or less and nut wt by 0.85 g or less by massive applications of over 10,000 lbs P/acre. Yield was not reported.

Occasionally P responses from seedlings grown in solution culture in the greenhouse have been reported. Omitting P from the nutrient solution in greenhouse grown pecan trees reduced plant N, P, K, Ca, Mg, Fe, Mn, B, Cu, Zn, Na and Al concentrations. These imbalances were only partially alleviated by foliar-applied P (Sparks 1986a). In the greenhouse, visible deficiency symptoms occurred only when no P was applied, but the best growth was with leaf concentrations of 0.19-0.22. Based on these data, Sparks (1988) concluded the recommended leaf analysis thresholds were too low. Field experiments, however, where two pounds of P/sq. ft. of soil surface were applied over two years only raised the leaf P to 0.16% (Sparks 1988). Obviously it is not practical for growers to have leaf P between 0.19-0.22.

POTASSIUM

Most Georgia orchards have been liberally supplied with K usually through annual applications. Since little has been removed in the crop, much of this K has been fixed or leached. Fertilizer trials on these orchards seldom indicate responses to K applications (Sharpe et al. 1950). In Tifton, Ga. studies, soil K is still in the medium range and yields have not been reduced significantly when no K has been applied in 20 years compared with annual applications (Worley 1994). Even on virgin soils of Georgia the first increment of 56 kg/ha/yr gave the highest yields compared with applications up to 224 kg/ha/yr (Worley 1991a). Some controversy exists concerning the lower threshold for the normal range. There has been no evidence from our studies to indicate that fertilization based on leaf thresholds higher than 0.75% were better than those based on 0.75% for bearing trees (Worley 1988a, 1988b). High K might give some protection of young trees to freeze damage to the trunks. Fall freeze damage to nuts was not related to N or K applications (Smith and Endicott 1983).

Applications of K usually increase leaf K, but the increase is small compared with the amount applied. In Louisiana, 50 lbs/acre/yr of potassium sulfate increased leaf K from O.81 to 0.85%, but soil K was increased from 120 to 292 lbs/acre (O'Barr et al. 1987a). Similar results were obtained in Oklahoma. Yield was increased in only one of six years and that was when leaf K was in the low 0.50s (Smith and Endicott 1983, Smith et al. 1985).

Solution culture of seedlings indicated K deficiency symptoms occurred at some point below 1.00% (Upson and Sparks 1969). Deficiency symptoms occurred at 0.30% and normal growth occurred at 0.85% (Upson and Sparks 1967), therefore the threshold for the low end of the deficiency range must be between these two points. I have seen deficiency symptoms in the field at 0.58% (Worley 1974).

LIME-pH

Carya species grow at widely varying soil pHs from 4.4 for *C. ovata* to 6.8 for *C. illinoensis* (Grauke et al. 1987b). Liming of acid soils to a pH of around 6.0-6.5 is usually recommended for pecans, but there is little research to support or reject the practice for old trees. Several reports indicate that young trees respond to lime applications. Greenhouse studies (White 1982) have shown increased seedling growth from lime amendments to the top and

subsoil. Roots grew best when lime was added to the subsoil to a pH of 6.5. Subsoil lime at 2 and 3 meq Ca/100 g soil (pH 6.0 and 6.5) increased yields of the small feeder roots 3 and 6 fold over the untreated check (subsoil pH 5.1). White (1982) concluded that acid subsoils can be an important factor limiting growth of pecan roots under soil conditions prevalent in much of the southeastern U.S. Increasing pH from 4.5 to 7.5 increased pecan seedling growth (Johnson and Hagler 1955). Deep placement of lime increased nursery seedling growth, but deep placement of complete fertilizer was no different from shallow placement (Robertson et al. 1959). In contrast, plant dry weight increased with decreasing pH for both mycorrhizae inoculated and uninoculated seedlings (Sharpe and Marx 1986). In field studies Worley (1991b) did not obtain growth responses when lime and fertilizers were added to the backfill soil at transplanting. In another study, the best yield was obtained from old trees when unlimed and the pH had dropped to 5.3 (Worley et al. 1974). The best yields were obtained from plots reaching a pH of 4.9 in Hunter and Hammar's studies (1947).

Liming to a high soil pH may be detrimental, because it reduces availability of many micronutrients, inducing zinc deficiency and possibly mouse-ear (Goff and Keever 1991, Keever et al. 1991) and induces the requirement for foliar zinc application. Hunter (1959) concluded that the major reasons for liming were to neutralize the acidity induced by applying ammonium nitrogen and to make the soil pH more favorable for growth of legumes. It takes 1.8 lb of lime to neutralize the acidity potential of each lb. of ammonium nitrogen. A good crop of crimson clover or similar legume can return 50-100 lb of N/A to the soil (Hunter 1959). Thus liming may indirectly help provide a slow release form of N and a food source for legume feeding aphids that are in turn a food source for pecan aphid predators. Zinc can be applied with lime satisfactorily, thus prevent lime induced zinc deficiency (Hunter 1959). Lime applied to the surface was slow to correct acidity in the lower profiles, therefore it should be incorporated into the soil (Hunter 1959). Liming at 2500 lb $CaCO_3$/A raised the pH from 5.3 to 6.2 in nine months while unlimed plots dropped to 5.0 (Hunter 1965).

Sometimes pecan nursery seedlings are grown in containers with various media that usually contain lime. O'Barr et al. (1987b) compared soil alone vs pine bark with lime added. Limed reduced leaf Zn and Mn. The best growth came from soil + an agriform tablet.

ZINC

In the 1920s and 30s the rosette disease was devastating pecan orchards throughout the pecan belt. The discovery that rosette is a zinc deficiency that can be rather easily corrected is a major factor in the recovery of the pecan industry.

Zinc deficiency inhibits chlorophyll synthesis, impedes stomatal conductance, and reduces photosynthesis (Hu and Sparks 1991). Mild Zn deficiency can be corrected by 5-10 lbs. $ZnSO_4$/tree (Brooks 1964, Hagler et al. 1957, Hunter 1960, O'Barr and Rachall 1987, Worley et al. 1972b, Young and Bryan 1966). Other effective sources of zinc are zinc oxide and the various chelates (Worley 1964, Worley and Harmon 1966, Worley et al. 1972b). Zn did not affect pH when applied at the rate of 10 lbs $ZnSO_4$/tree (Hunter 1965). Soil Zn applications may correct deficiency for several years (Gossard and Parson 1941).

Most forms of zinc become immobile soon after soil application which means the zinc must be placed in contact with the feeder roots or the feeder roots must grow into the soil containing the zinc. For this reason soil applied zinc is sometimes slow in moving into the tree. It took three years after a Zn application to measure a significant increase in leaf Zn (Hunter 1965). Leaf Zn was lower when lime + Zn was applied than when Zn alone was applied (Hunter 1965). Ten lb of $ZnSO_4$/tree maintained the soil at a high level of Zn for nine years. Leaf Zn increased with time after a Zn application, while the control averaged 36-55 ppm. Yields were not affected. Close attention to soil pH seems to be the most practical answer to Zn problems (Hunter 1965). One grower induced zinc deficiency by applying laying hen manure. This manure contained a high portion of oyster shells which had been fed to the hens to strengthen the eggshells. The calcium carbonate from the oyster shells raised the pH, making Zn unavailable (Worley et al 1972b).

The fastest way to correct zinc deficiency is by trunk injection (Gossard and Parson 1941, Worley et al. 1980). When zinc is pumped into the trees, it should be in the leaves within minutes. Injected dyes have been found in the top of a tree within an hour of the start of injection. A rate of 1 g of zinc sulfate per inch of trunk diameter has given good results (Dutcher et al. 1985, Worley et al. 1980). Small pressurized cartridges of ZnEDTA were not effective, because they supplied insufficient Zn (Storey et al. 1971, Worley et al. 1980).

Zinc sulfate sprays were effective in some years (Alben 1962, Worley et al. 1972b, O'Barr 1987, O'Barr and Rachal 1987). Zinc chelate sprays have been effective (Alben, 1962).

Nitrogen seems to be an adjuvant for increasing zinc absorption from sprays (Smith and Storey 1979, Storey et al. 1975, Grauke 1982, Grauke et al. 1982). Sprays of NuZ were not effective (Hagler et al. 1957). Soil applied zinc chelates corrected a deficiency within one year (Worley et al. 1972b).

In acid soils, broadcast application is preferred over band application. When equal amounts of Zn/tree were applied more was taken up from the broadcast than from the band

application. Zinc was increased above the sufficiency level by ≥40 kg/ha when broadcast and ≥3.2 kg/tree when banded in a 51 cm band (Payne and Sparks 1982).

In high pH soils, soil application of Zn has not been satisfactory. Soils with only 86 lbs Zn/acre-6-inches, but with a pH of 6.10 to 5.75, did not have rosetted trees, but trees on soils with higher pH or lower Zn concentration were rosetted (Alben and Boggs 1936). Neither zinc sulfate, zinc chelate, deep placement or application of sulfur to reduce pH satisfactorily increased Zn in Texas studies (Storey and Anderson 1970). They found that several zinc sprays to the foliage with ground sprayers was the most satisfactory way of getting Zn into the tree. Zinc sulfate was a better source than zinc oxide or NuZ in their studies. They suggested using 3 lbs of zinc sulfate/100 gallons of water and spray to runoff at monthly intervals beginning when leaves are one-third grown. Ground applied sprays were more effective than aerial applied sprays.

Zinc must be in solution to be absorbed from foliar sprays. Leaves should remain moist as long as possible. A high relative humidity is beneficial. Ground equipment applies more water and is preferred over aerial application. A minimum zinc aerial foliar application to mature pecan trees in semi-arid far west Texas has been set at 10 lbs elemental Zn in at least 20 gal of water/acre in three applications starting with young two-thirds developed leaves and continuing at 30-day intervals thereafter. In the humid Red River Valley 800 miles away in northeast Texas only 2.7 lbs of elemental zinc in 5 gal of water was sufficient for adequate zinc absorption (Storey and Anderson 1969).

In calcarious soils of Texas, acidification of <1% of the effective root zone of a mature pecan tree by applications of sulfuric acid and zinc sulfate to a shallow trench under the tree, increased Zn uptake and maintained elevated Zn in leaves for nine years. The acid band lowered soil pH to a depth of 60 cm and increased solubility of Zn. Tree roots did not grow into the acidified band, presumably due to high salinity, but proliferated extensively at the interface of the acidified band and calcarious soil (Fenn et al 1990).

It is apparently the high pH and not the calcium that restricts Zn uptake. In sand culture studies, zinc concentrations of 0.1, 1, and 10 ppm Zn and Ca concentrations of 1, 4 and 16 me/l were compared. Increasing Zn from .1 to 10 ppm increased growth and leaf Zn. Increasing Ca rates had no effect on shoot growth except at the high rate of Zn, but leaf Ca was increased. Increasing Ca up to 4 me/l in the nutrient solution actually increased leaf Zn content, but higher rates reduced leaf Zn. The highest shoot growth was made at the highest levels of Ca and Zn (Hagler et al. 1958).

Georgia uses 50 ppm Zn as the lower threshold for leaf analysis (Plank 1988). Several studies support this threshold. At Byron, Ga. all areas showing trees with zinc deficiency were <40 ppm in leaf Zn (Sparks and Payne 1982). Additional modeling studies confirmed that nut yield and vegetative growth in an orchard will be reduced with a leaf Zn concentration of <40 ppm, but will be unaffected above this value (Sparks 1993a). The threshold of 50 ppm appears desirable for orchard samples, since they probably have some leaves in the sample that are normal. Leaves showing Zn deficiency usually have less Zn than random orchard samples in an orchard with Zn deficient trees (Sparks 1993b).

CALCIUM

Most orchards of improved cultivars have been limed. Few, if any, instances of calcium deficiency in the field have been confirmed. Greenhouse studies in sand culture indicated that Ca deficiency symptoms occurred when leaf Ca was below 0.5%. Growth increased rapidly to a leaf concentration of 0.70% and more slowly as leaf Ca increased to 1.7% (Sparks 1986d).

MAGNESIUM

The magnesium nutrition of pecan has been reviewed by Sparks (1976c) who indicated soil levels in excess of 120-200 lbs/acre and leaf concentrations in the range of 0.3-0.6% should supply adequate Mg. Magnesium deficiency is fairly rare if there is a history of dolomite application, but it has been reported in several areas of Georgia and Alabama. It is observed more frequently on sandy soils than on heavier soils and can be intensified by applications of N or K (Worley 1975). In Florida, increasing rainfall in Jan-May causes shallow root growth in the topsoil where the Ca/Mg ratio is higher and reduces leaf Mg (Gammon et al. 1960). Once orchards become deficient, it may take several years to correct the deficiency. Magnesium sulfate and magnesium nitrate sprays were ineffective (Worley 1975). Sprays of Solu-Mag increased leaf Mg, but leaves were still deficient (Worley 1982). Broadcast magnesium sulfate was the treatment that increased leaf Mg most, but trees were still deficient after five years of annual applications. Dolomite increased soil Mg but not leaf Mg during the study (Worley 1975).

SULFUR

Most orchards have received applications of sulfur as ingredients of fertilizers and pesticides. Many growers have been applying sulfur and have been making claims of responses, but I know of no reports from replicated field trials of pecans responding to sulfur application as a plant nutrient. We did not obtain responses from limited trials. Solution culture studies of N and S interactions indicated N and S deficiency symptoms at concentrations of <2.5 and 0.14%, respectively. Photosynthesis and growth were reduced at concentrations >3.5 and 0.37%, respectively. A

N/S ratio of nine appeared optimum. A survey of pecan orchards in Georgia and Texas indicated that they might respond to S applications (Hu and Sparks 1992).

In solution culture studies, the first symptom of mild S deficiency was fading of the interveinal areas in the regions between the minute veins. This fading continued until the leaflet was uniformly yellow with only the main veins remaining green. In some cases the areas between the minute veins regreened. Sometimes the yellowed areas developed a reddish brown tinge. Newly emerged leaves were golden yellow and did not green. Tips of new leaves turned downward and margins upward. Emerging leaves became progressively smaller and internodes shorter until elongation ceased and the apical meristem died. Veins of smaller leaves became necrotic, which started as a rusty discontinuous browning but later became continuous. In severe cases, the midrib died from the apical end, followed by death of the leaf blade. Chlorophyll concentration and growth increased curvilinearly with leaf S and had not peaked at 2.7 mg/g dry weight (Hu et al. 1991).

Sulfur deficiency greatly increased the free amino acid pool (mainly arginine). The concentration of free amino acids decreased exponentially with increasing leaf S. Protein amino acid concentrations (mainly methionine) increased with increase in leaf S (Hu and Sparks, 1991).

IRON

Iron deficiency shows up as light colored foliage with interveinal chlorosis mainly in the spring. The occurrence is very sporadic and trees usually green-up when temperature rises in the spring. Its inconsistency makes it difficult to research. Foliar sprays are frequently applied, and trunk injections have been tried, but replicated trials have been few. Sequestrene 330 iron chelate foliar spray did not correct Fe deficiency (Sparks 1976b). The material

"Harvest-Plus" increased seedling leaf, stem, and root Fe but had no effect on growth (Sparks 1986c).

MANGANESE

There are few, if any, instances of manganese deficiency of pecans in the field. Manganese can reach high concentrations in pecan leaves without injury. Soil drenches of increasing concentrations of a manganese chelate reduced leaf Zn and increased leaf Mn to concentrations of 4525 ppm. Concentrations of 2800 ppm were not phytotoxic but the next level (4525 ppm) was phytotoxic (O'Barr et al. 1987c).

A survey in Australia revealed leaf concentrations varying from <40 to >400 ppm Mn with no foliar symptoms of deficiency. Larger leaves had lower concentrations of Mn than smaller leaves. There was good correlation between total Mn/leaf and leaf area/leaf and suggests that total Mn/leaf might be a better measure of Mn nutrition than concentration in ppm. Average leaf moisture/leaf and total Mn/leaf were also highly correlated (Cornish 1964).

COPPER

There are few, if any, reports of a response to additions of Cu for pecans. In Florida Cu ranged from 6-9 ppm (Van Lam et al. 1978). Samples from our plots are similar. Applications of copper sulfate to supply the equivalent of 0, 1, and 3 ppm Cu for a 15 cm depth and 2 m radius caused an increase of <2 ppm leaf Cu and <2 ppm of extraxtable soil Cu in three years. Tree growth was not affected significantly (Van Lam et al. 1978).

BORON

There is no known problem with boron deficiency of pecan in the field, however a few instances of toxicity have been reported. Occasionally toxicity can occur when boron is used in the home laundry and the wash water goes into a septic drain field near pecan trees (Worley 1991c) or the irrigation water is high in boron (Smith 1991a). Leaf boron has been increased by foliar sprays of CaB or Harvest-Plus (Sparks 1986c).

In sand culture, weight of tops and roots was greater when solution contained 1/2 ppm B than no B (Blackmon 1941b). In solution culture, leaf B increased linearly with increased concentration in the soil saturation extract. Boron toxicity occurred within several weeks after applications of $\geq$1.25 mg/l. Leaves with no visible injury contained <325 mg B/kg dry weight. Boron damaged leaves contained a minimum of 900 mg/kg (Picchioni et al. 1991).

TIME OF FERTILIZER APPLICATION

Late winter or spring is usually considered the time for fertilizer application. The idea is to have the nutrients available for the spring flush of growth. Recent research indicates that the spring flush is mainly nourished from reserves. The importance of having the fertilizer applied in spring is less than once thought (Sparks and Baker 1975, Sanchez et al. 1991). Summer N application increased January twig N concentration over spring applications (Blackmon 1941a).

Hunter and Lewis (1942) found that the largest increase in growth and yield was when fertilizer was applied in six small applications, but time of application had no significant effect on yield. Quality of nuts was poorest when trees received 1/2 the fertilizer in February and 1/2 in June, and best when trees were unfertilized. Growth and yield were increased by N applications, but both February and December applications were equally effective (Hunter 1964). An October 1 application was as good or better than a March 1 application in Oklahoma (Smith 1991b). Another

report (Harmon 1963) indicated March 1 applications were better than applications on April 1, May 1, or June 1. Timing is sometimes determined more by convenience rather than efficiency. Nutrients can be applied at any time of the year and be effective. Winter is convenient for commercial applicators, since their equipment is less busy. Frequent and heavy rains in February and early March contribute to leaching and runoff loss of soluble nutrients applied prior to their occurrence. For this reason I prefer to wait until mid-March to apply nitrogen.

FOLIAR APPLICATION

Soil application is usually the most practical way to supply plant nutrients. However there are some instances where foliar applications might be practical. Zinc in high pH soils is too insoluble for root uptake and must be foliar applied (Storey et al. 1975, Worley et al. 1972b). Young leaves absorb Zn at ten times the rate of old leaves. Absorption seems to be greatest through midribs and young buds (Storey et al. 1975). Uran (32% N solution from Urea and ammonium nitrate) was an excellent adjuvant for increasing Zn uptake (Storey et al. 1975). Aerial application of zinc was not as effective as ground equipment (Storey et al. 1971). Raising the pH of the spray solution could reduce the absorption of Zn. The best absorption was at pH 5 and 6 (Rutland and Sparks 1966).

Attempts at foliar application of macronutrients have not been very successful. Nitrate of potash sprays increased yield of 'Moore' in one year but did not affect yield of other cultivars or kernel percentage of any cultivar. Oil content was increased by a maximum of 2.5 percentage points on some cultivars in some years (Hunter 1966, 1967). In Oklahoma, foliar applications of potassium sulfate and potassium nitrate were ineffective in supplying K to pecan trees (Smith et al. 1987). Gossard and Nevins (1965) increased leaf K by spraying potassium nitrate, but yield and quality were not affected. Harvest-Plus (containing N, P, K, Mg, S, Zn, Mg, Fe, Cu, B and Mo) increased Fe, Mn, B and Zn but had no effect on other nutrients in leaves (Sparks 1986b). CaB foliar sprays increased foliage B (Sparks 1986b).

Foliar applied P from KH_2PO_4 in greenhouse studies suppressed or prevented P deficiency symptoms, increased the P concentration in the leaf, trunk and root, and increased tree growth. Phosphorus in all three tissues was less for trees receiving foliar sprays than for plants with root-supplied P. Also, P sprays eventually produced leaf scorch (Sparks 1986a).

Foliar sprays of 0, 2, 4, and 8 lbs magnesium sulfate/100 gal. water applied twice weekly to greenhouse grown pecan seedlings for a total of 20 sprays increased leaf Mg from 0.06% to 0.20% but still did not correct Mg deficiency. Leaf Mg was 0.55% when Mg was root supplied (Sparks 1985). He suggests foliar Mg sprays might be used to correct mild Mg deficiency. Applications to old trees in the field increased leaf Mg very little if any (Worley et al. 1975, Worley and Littrell 1980).

Zinc sprays were equally effective when applied to either the upper or lower leaf surface. Old leaves did not absorb Zn (Wadsworth and Storey 1970).

Grauke et al. (1982) obtained similar Zn uptake from applications to either the upper or lower surfaces. Increasing relative humidity also increased uptake (Grauke et al. 1984) which further supports night applications when relative humidity would be higher.

AREA OF APPLICATION

Fertigation is of great interest, since it provides a means of spoon feeding nutrients to pecan trees and gets the soil compacting fertilizer truck out of the orchard. The total area of the orchard is seldom wet by sprinkler or drip irrigation systems, therefore for fertigation to be satisfactory in these situations, the fertilizer would have to be effective when applied to a limited portion of the orchard floor. Limited research has indicated that N can be efficiently taken up when applied over a small portion of the orchard floor. Apple tree /performance was the same when fertilizer was applied to the whole area and to the herbicide strip only (Kulesza and Szafranek 1990). No detrimental effect was noticed when N was concentrated within areas of 30, 25, 20, and 15 feet from the pecan tree trunk (Worley 1989a, 1989b). No differences in leaf N were obtained when N was broadcast or applied along the dripline of apples (Michaelson et al. 1969).

FERTIGATION

Fertigation can be defined as application of plant nutrients through the irrigation system. The advantage is that the trees can be fed small amounts of nutrients at frequent intervals, thus avoid leaching losses. Compaction caused by application equipment would be eliminated. One possible disadvantage is that the nutrients go where the water goes and some areas of the orchard might be missed. Aitken (1986) reduced N and K rates by two-thirds without detrimental effect. Our tests at Plains, Georgia on mature trees indicate that 50 and 100 lbs/acre N all applied through the irrigation system are adequate and as good as twice this amount applied broadcast (Worley et al. 1990a, 1990b).

One concern for drip fertigation is the reduction in soil pH in the wetted zone around emitters (Edwards et al. 1982), but both Aitkin (1986) and Worley et al. (1990a, 1990b) did not notice a pH drop. The pH outside the wetted zone was lowered by broadcast applications (Worley et al. 1990a, 1990b).

MOUSE-EAR

A malady referred to as "mouse-ear" has been a mystery to pecan growers for years. It is characterized by small rounded leaflets mainly on first-flush foliage. Second flush foliage is usually normal. Sometimes spring growth consists of leaf rachises without leaflets. It appears most frequently on young trees that may grow out of the condition, but it can occur on older trees. Sometimes young trees will be mouse-eared while older trees in the same orchard will be normal. Sometimes only certain limbs on a tree are affected. Mouse-ear was once thought to be a Mn deficiency (Gammon and Sharpe 1956), but now it is obviously not the only cause.

Several attempts have been made to relate mouse-ear to mineral nutrition. Grauke et al. (1987a) reported that mouse-eared leaves were higher in N, P, Ca, S and Mn and lower in Fe than normal leaves. All leaves appeared low in N and K and high in Zn. These were leaves from pot grown seedlings with media pH of 4.5. They attributed mouse-ear to over fertilization with N in an acid media.

Goff and Keever (1991) were able to correct mouse-ear in pot grown seedlings by omitting lime from the growing media. The greatest plant recovery occurred when no lime was added resulting in a pH of 3.9 in bark-sand and 4.2 in soil-peat-perlite media. Increasing lime increased leaf Ca, Mg, P, B (quadratic), and Fe and reduced leaf MN, Cu, and Zn (quadratic). In another study (Keever et al. 1991) that varied lime rates from 0 to 11.9 kg lime/m^3, indicated a lime rate of 3.0 kg/m^3 produced the best growth with few mouse-ear symptoms. Low pH would increase availability of Cu, Mn and several other elements.

Some verbal reports have related mouse-ear to a Cu deficiency, but published reports from replicated trials are not available yet. In Goff and Keever's study (1991), mouse-eared leaves were higher in Cu than normal leaves. In our studies of 'Schley' and 'Mohawk' normal leaves were higher in Cu than mouse-eared leaves while normal and mouse-eared leaves of 'Desirable' and 'Wichita' were about the same (Worley 1979). Gallaher and Jones (1976) found more Ca, Mn, Fe, Cu, Zn, and Mo and less Mg in mouse-eared leaves than in normal leaves and soil P, K, Ca, Mg, and Zn was greater under mouse-eared trees than normal trees. The data is confusing, but high lime or high pH seems to increase mouse-eared leaves.

FOLIAR ANALYSIS

For leaf analysis to be an effective tool, the deficiency—normal and toxicity—ranges for each nutrient must be determined. Sparks (1978a, 1984) grew pecan seedlings in nutrient solutions with and without each of the nutrients. Omitting any nutrient suppressed growth. Omitting any nutrient except Fe, Mn and Cu induced deficiency symptoms. Mean concentrations when the nutrient was omitted and added respectively are as follows: N=1.66 and 3.10%, P=0.08 and 0.23%, K=0.44 and 1.65%, Ca=0.12 and 2.51%, Mg=0.08 and 0.64%, S=0.08 and 0.33%, Fe=102 and 126 ppm, B=6 and 41 ppm, Cu=18 and 20 ppm, and Zn=31 and 37ppm. The critical concentration (i.e. the concentration above which responses from applications could be expected) for each nutrient would be somewhere between these two concentrations. Obviously there were problems with Cu and Zn, because copper levels were higher for both treatments than in most field samples and there was little difference in the + and - zinc treatments. Zinc deficiency was present in the complete nutrient solution. Concentrations of most elements (not Zn) grown on the complete solution were high compared with most field samples. A field study comparing orchards, one in a high and one in a low nutrition status revealed concentration of Zn, Ca and Mg were higher in the high orchard, but K was inconsistent and N concentration was higher in the low orchard.

Sparks (1978b) concluded that deficiency symptoms occur at levels of 2.3% N, 0.10% P, 0.60% K, 0.40% Ca, 0.20% Mg, 0.10% S, 50 ppm Mn, 20 ppm Zn, 6ppm B and Cu. Leaf levels for optimum growth were 2.7-3.0 N, 0.14-0.30% P, 1.25-1.5% K, 1.0-2.5% Ca, 0.40-0.60% Mg, 0.20-0.50% S, 100+ ppm Mn, 65+ ppm Fe, 50-100 ppm Zn, 15-50 ppm B, and 10-30 ppm Cu. The current sufficiency range used for Georgia is: N=2.50-3.30%, P=0.12-0.30%, K=0.75-2.50%, Ca=0.70-2.50%, Mg=0.30-0.60%, S=0.20-0.50%, Mn=100-800 ppm, Fe=50-300 ppm, B=15-50 ppm, Cu=6-30 ppm, Zn=50-100 ppm, and Al=<2000 ppm (Plank 1988).

Attempts have been made to standardize the procedures for collecting leaf samples. Georgia has settled on the second week of July through the first week of August as the best time to sample (Sparks 1970, Worley 1977, Worley and Mullinix 1977). Auburn used the last week of May through the first week of June (Amling and Turner 1964). Malstrom and Reiley (1984) concluded there was not a consistent pattern among nutrient levels as influenced by time of sampling but mid-season was found to be satisfactory.

Georgia and Alabama use the middle leaflet of middle leaves around the periphery of the tree as the part sampled. The leaf position is apparently not important for N but is important for other nutrients. Nutrient concentration varied widely by leaf node position and was different for Zn, K, Ca and Mg, but N concentration was independent of leaf position. Nutrient concentration for leaflets on leaves was generally different for Ca, Mg and Zn, whereas K and N were generally independent of location of leaflet on leaf (Malstrom and Riley 1984).

It is apparently not necessary to distinguish between fruiting and vegetative shoots. Fruiting shoots produced larger leaves, but nutrient levels were not consistently higher than those of vegetative shoots (Malstrom and Riley 1984).

Alabama reported that only deficiencies of N, Mg, Zn, and Fe have been correlated with visual symptoms in pecan orchards (Amling and Turner 1964). They suggested the following normal ranges: N=2.70-2.90%, P=0.14-0.30%, K=0.75-0.95%, Mg=0.40-0.60%, Ca=0.70-1.50%, Zn=50-99 ppm, Fe=100-250 ppm, and Mn=350-1000 ppm. Lane et al. (1965) found Zn deficiency symptoms when leaf Zn in greenhouse nutrient solution studies reached 20 ppm.

MYCORRHIZAE

Pecan roots have no root hairs, therefore the symbiosis with ectomycorrhiza is important to pecan nutrition. Inoculated seedlings had greater total plant dry weight and uptake of N, P, K, Ca, Mg, Cu and Mn than noninoculated seedlings. Mycorrhizae might also improve the trees performance at low pH. Mycorrhizae developed better at pH 5.5 than at 6.5 and the percentage of infected roots increased from 22 to 44% as soil pH decreased from 6.5 to 5.5. Plant dry weight increased with decreasing pH for both inoculated and uninoculated seedlings (Sharpe and Marx 1986). Mycorrhizae might be responsible for the seemingly good nutrition of old pecan trees at low pH.

DRIS

DRIS is a method of determining deficiencies or excesses of nutrients in plants based on the relative concentrations of nutrients with each other. It has received a great deal of attention for other crops, but recently its usefulness seems to be waning. For hazelnuts, DRIS did not detect all deficiencies or excesses and was best viewed as a supplement to sufficiency range diagnoses that provides additional information when severe imbalances are detected (Alkoshab et al. 1988). Beverly and Worley (1992) determined DRIS indexes for pecans, but insufficient data showing positive responses from fertilization was available to test DRIS against critical values.

MISCELLANEOUS NUTRITIONAL SOURCES

Fluidized bed combustion residue (FBCR) is a combustion residue from a calcitic limestone source, a by-product of scrubbing SO_2 from fossil fuel fired boilers. The material was more effective in neutralizing soil acidity and increasing extractable soil Ca than agricultural calcitic limestone. FBCR may be applied to pecan trees without inducing nutrient imbalances or toxicity from the heavy metals contained in the FBCR. In pecan leaves it increased calcium and decreased Mn, Al and Zn concentration (Edwards et al. 1985).

Sewage sludge contains slowly available nutrients but is sometimes high in toxic lead and cadmium. An application of 2.5 and 5 tons/acre increased yield 14 and 25%, respectively, compared with 41% with 150 lbs N, 22 lbs P and 62 lbs K from commercial fertilizer (Anon. 1992).

Animal manure in early studies (Blackmon 1936) produced some of the highest yields, and when available, could be a good source of nutrients as well as a place to dispose of the by-product.

Legumes are excellent sources of N. In Oklahoma studies, a legume mix provided 100-186 kg N/ha (Rice et al. 1993, 1994) in addition to reducing the pecan aphid population.

LEAF SCORCH

There are several leaf scorch maladies affecting pecans that have sometimes been attributed to nutritional imbalances. When 'Chickasaw' fruits heavily, leaves scorch and drop off in the fall. This type of scorch was first attributed to insufficient K (Sparks 1977a) and later to insufficient P (Sparks 1989b).

Scorch is sometimes severe, especially on young 'Desirable' trees in late spring and summer. Sparks obtained data on low wet soils near Waycross, Georgia to indicate that scorch was more severe at high rates of N combined with low rates of K (Sparks 1976a). The term nitrogen scorch was coined to describe the malady. This symptom has also frequently been observed on trees liberally supplied with K. Sometimes water logged trees or trees with cold injury or borer damage show the symptoms. Applications of 112 vs 224 kg/ha N and 0-224 kg/ha K showed little relationship of N, K, or the N/K ratio to the malady (Worley 1983, Worley 1990b). The correlation coefficient for the leaf N/K ratio and leaf scorch was practically zero for tests at two locations. A Potassium deficiency or high N might cause scorch in some instances, but apparently other things can cause the malady.

NUTRITIONAL MALADIES

A seedling dieback was noticed when seedlings were grown in nutrient culture. All seedlings receiving deionized water died back. Twenty-three percent died back in the minus B treatment, 82% when Ca was omitted, and none when treated with a complete nutrient solution (Sparks 1977b).

VARIETAL DIFFERENCES

There appears to be some cultivar differences in nutrient content for various cultivars fertilized similarly (Worley 1977, Sparks and Payne 1978, Worley and Mullinix 1993). It is not known whether these differences are great enough and consistent enough to warrant differential fertilization for cultivars. 'Desirable' has a lighter color than 'Stuart' that may be related to a lower leaf N and higher leaf K, Ca, Mg, Mn, B, Cu, and Zn (Sparks and Payne 1978).

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BREEDING IMPROVED PECAN SCION CULTIVARS

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ABSTRACT

Pecan breeding remains a long-term genetic improvement process. It produces high yield returns per research dollar invested. This paper describes the USDA-ARS pecan genetics and improvement program to develop improved scion cultivars. Some discussion of breeding theory and strategies is also included.

Pecan is diploid (n = 16), monoecious, and heterodichogamous. The complete heterodichogamy of pecan makes it almost completely cross-pollinated, resulting in very high heterozygosity with severe inbreeding depression when selfed. Hybrid vigor has been selected naturally in the evolution of this species. Pecan seems to be a naturally vigorous, wood-producing tree.

From a breeding standpoint, we know more about agronomic crops which are usually annuals than about tree crops that have much longer generation times. Impressive improvement has been obtained in pecan through selection, in only a few cycles of crossing. In other crops, breeding cycles usually mean more than one generation and usually involve selfing.

Every species has advantages and disadvantages to improvement through breeding. For instance, in maize (corn) breeding, a single good plant may be developed in a relatively short time, but there remains the problem of mass reproduction of this plant, while at the same time maintaining hybrid vigor and uniformity. In maize, this involves utilizing cytoplasmic male sterility to make the hybrid reproducible. This takes time to perfect in the hybrid combination desired. In breeding annual crops, a large portion of breeder time is spent perfecting a system to allow this reprocuction.

In pecan, by contrast, a single improved clone takes years to test, but during this testing phase, plants are genetically stable, since the genes of the clone are fixed. They do not change since asexual propagation (budding and grafting) is used to increase the number of individual trees. As a result, genetic variability is zero in evaluation trials.

As mentioned earlier, pecan is diploid. This makes genetic selection more direct for both qualitative and quantitative characters. Hopefully, we can determine segregation ratios for more simply inherited traits in the future. For example, a single gene determines type of dichogamy in pecan. This knowledge is used to produce either protandrous or protogynous clones in the breeding program as needed. There may also be specific genes conditioning resistance to different races of the scab organism. The inheritance of many other traits is probably quantitative. Included here are such things as precocity, length and time of season of nut fill, and some disease and insect resistance mechanisms.

The ideal pecan cultivar should also make regular crops of high quality nuts. A major challenge in current orchards is the exaggerated pattern of alternate bearing. One possible strategy to achieve the goal of regular production is by selecting early maturing cultivars and selection for distribution of the crop throughout the canopy. Also, nut quality is difficult to maintain in very large fruited cultivars. Moderate size nuts (6-9 g/nut) borne in clusters of moderate size (2-4 nuts/cluster) that are well distributed throughout the tree, may facilitate consistent production of quality pecans. Trees which mature nuts in September may have the ability to regenerate exhausted energy reserves prior to dormancy, allowing for more consistent return crops. In addition, early pecans often receive higher prices, and generally mature under more favorable harvest conditions.

For its future economic survival, we believe the improved pecan industry needs high yielding, precocious cultivars. Cultivars should begin to bear in 4-5 years rather than 7-8 as in many older cultivars. Pecan orchards are capital intensive, long-term investments which become increasingly hard to justify as the length of time to economic return increases. Precocious cultivars are therefore a necessity. Increased yields are required to provide the incentive to bear the risk of orchard management. Currently, the costs of managing an improved pecan orchard in the southeastern United States are only barely exceeded by the sale of the crop (Wood et al. 1990). The most direct methods of addressing that situation by breeding are to increase the size and quality of the crop. Madden and Malstrom (1975) stressed the need for trees capable of being grown at high densities. Cultivars are currently being evaluated for differences in productivity as a function of tree size and shape. Ultimately, it is the responsibility of state researchers and pecan growers to develop orchard configurations which optimize productivity under existing management constraints.

Since most pecans are shelled before they are sold to the consumer, the ideal nut is one which performs best for shelling. Desirable attributes of shelling pecans were described in detail by Romberg (1968). The ideal nut shape is moderately elongated with a symmetrically rounded (not angular) apex and base. Shells should be thin, but not to the point of being damaged by routine harvest or handling

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procedures. Sutures of the shell should not separate before harvest or during normal handling. When cracked, kernels should separate easily from the shell without adherence of shell parts. Kernels should be "golden" to "light brown" in color, to use the terms of the National Pecan Growers Association Standards. Other industry terms for those colors include "bright", "cream", "light amber", and "fancy". Kernels should be of good edible and storage quality and free of adhering "fuzz" (residual ovarian wall tissue), even when poorly filled.

Ideal cultivars will require a minimum of management input for the control of diseases and insects. Disease resistance has long been recognized as a necessity for the humid Southeast and has been a high priority of the breeding program as outlined by Crane et al. (1937), Romberg and Smith (1950), and Romberg (1968). Unless disease resistant cultivars can be developed, the southeastern pecan growing region is in jeopardy. The high economic and environmental cost of routine fungicide sprays places that region at a tremendous disadvantage in relation to the arid southwest where disease pressure is reduced. The challenge of developing disease resistant cultivars lies in thoroughly evaluating potential clones for disease resistance prior to release. This challenge has been addressed in the formation of the advanced selection testing program, and in the establishment of the College Station Pecan Breeding and Genetics Research Unit in humid East Texas.

Improved cultivars must be propagated on resilient rootstocks which contribute to the productivity and longevity of orchards, being adapted to both the climatic and edaphic region in which they are planted. As a first step, rootstock as a variable should be recognized and controlled in research and test orchards, as is the current practice in our test orchards. Improved rootstocks can be incorporated and tested as a normal part of scion clone evaluation.

CURRENT BREEDING PROGRAM

The U.S. Department of Agriculture, Agricultural Research Service, in cooperation with state agricultural experiment stations, state extension services, and private growers, conducts the only pecan breeding program in the world. The breeding efforts at the USDA Southeastern Fruit and Tree Nut Laboratory, Byron, Ga., are an important part of this single breeding effort to produce improved cultivars.

All of the above improvement dialogue relates to populations and fairly large numbers of plants. We feel that to continue the pecan breeding success, we must test large numbers of seedlings. The probability of producing a cultivar with a minimum level of genetic traits is the product of the individual probabilities. For example, if the probability of the progeny having at least a kernel percentage of 55 is .25 and the probability of nut size being at least 8 g is .5; then the probability of any clone produced meeting both these selection criteria is (.25) (.5) = .125, or 1 in 8. Thus 7/8 of the clones would be discarded. Additional genetic requirements would lessen the selected proportion. This is why we have essentially two selection cycles: the Basic Breeding Program (BBP) and the National Pecan Advanced Clone Testing System (NPACTS). Large numbers of seedlings are produced and eliminated in BBP based upon highly heritable, easily selected characteristics, while NPACTS tests are longer and test more for yield as mature trees.

The following selection scheme is currently being used:

Phase	Description	Years	No. Clones	Spacing (ft.)
I	Seed Production from crosses	1	5,000	—
II	BBP	10	5,000	10 X 15
III	Scab Screening	1	50	cont.
IV	NPACTS	15	5-10	35 X 35

PHASE I

The traditional crossing technique is used to produce up to 5,000 seed each year. Parents are selected on the basis of production, quality, and other performance considerations, recognizing that different geographic regions of the pecan industry have different requirements. The 20 cultivars released by the program (Table 1) represent the following 21 parents (with the number of released progeny in parentheses): 'Alley' (1), 'Barton' (2), 'Brooks' (2), 'Burkett' (2), 'Carmichael' (1), 'Clark' (1), 'Curtis' (1), 'Desirable' (2), 'Evers' (4), 'Halbert' (1), 'Mahan' (5), 'Major' (1), 'Mohawk' (1), 'Moore' (1), 'Odom' (2), 'Risien #1' (1), 'Schley' (5), 'Success' (4), 'Starking Hardy Giant' (1), 'Wichita' (1), USDA Selection 48-13-311 ('Moore' × 'Schley') (1). The 21 parents represent clones from six states: Florida ('Curtis' and 'Moore'); Georgia ('Brooks'); Kentucky ('Major'); Mississippi ('Alley', 'Desirable', 'Mahan', 'Odom', 'Schley', 'Success'); Missouri ('Starking Hardy Giant'); Texas ('Burkett', 'Carmichael', 'Clark', 'Evers', 'Halbert', 'Risien #1', 'Wichita', 48-13-311). Four parents, 'Barton', 'Mohawk', 'Wichita', and 48-13-311 are products of the U.S. Department of Agriculture breeding program. The parents reflect a broad range of the species distribution. Seven of the parents ('Burkett', 'Carmichael', 'Clark', 'Evers', 'Halbert', 'Major', and 'Starking Hardy Giant') are direct selections from native populations. Therefore, adequate genetic diversity is presently maintained. To some extent, progeny are used in the area of parental origin.

Crosses are made at Brownwood and College Station, Texas. The large amount of seed is possible due to im-

proved techniques of tree preparation and care, so that each crossed cluster produces more seed. Some trees in our crossing program routinely produce 2-4 nuts per cluster, compared with the average of less than 1 per cluster a few years ago. Seed from controlled crosses made in the breeding program is collected from mature clusters, numbered to reflect the year, parentage and seed number, and individually weighed and measured. Nuts are stratified for six weeks at 3C, then planted in the greenhouse. Height and stem diameters of young trees are recorded. Young seedlings are transplanted to the field during their first dormant season which begins Phase II (BBP) and are evaluated for 10 years.

PHASE II - BASIC BREEDING PROGRAM

Phase II, the BBP, is the initial field selection phase at Brownwood and College Station, Texas; for yield, precocity, nut quality, desirable leaf and tree structure, disease and insect resistance, etc. These trees are grown at relatively close spacing, and we plan to eliminate trees beginning in the 6th or 7th year based upon precocity, nut size, etc. This early elimination will allow more room for the more desirable clones to develop and be more adequately evaluated.

Seedlings are evaluated for resistance to scab and other diseases when they develop sufficiently in the breeding nursery. Nuts are harvested and a nut sample is evaluated. Measurements include nut weight, nut volume, nut length and width, kernel weight, and kernel color. Samples are also rated for adherence of packing material and fuzz. Initial selection is on the basis of yield, precocity, nut size, % kernel, shelling quality, and scab resistance. Threshold levels of nut measurements for initial selection, regardless of target region, are 7 gm/nut and 55 % kernel, with wide and open dorsal groove formation which permits complete removal of shell particles. Only 1 or 2 of these clones are saved per thousand for Phase III or Phase IV NPACTS testing.

PHASE III

The purpose of this phase is to determine the scab resistance level of superior clones from Phase II. Through a cooperative agreement between The USDA-ARS Southeastern Fruit and Tree Nut Research Laboratory at Byron, Ga., and Simpson Nursery of Monticello, Fla., 50-100 clones are grafted onto container trees, and these stions are grown in a severe scab disease environment. Resistant clones are identified and these trees are transplanted to the field at the Byron Lab and at other NPACTS sites where they undergo further production testing (Phase IV, NPACTS, described below).

PHASE IV - NPACTS

In NPACTS, elite clones from Phase II and III are tested in replicated trials across the entire pecan belt, mainly for environmental adaptation. NPACTS consists of four testing areas, each with a horticulturist conducting this testing work:

Area	States	Scientists in Charge
Area I	Fla. Ga. Ala.	Dr. Morris Smith, Byron, Ga.
Area II	La. Miss.	Dr. Mike Smith, Stoneville, Miss.
Area III	C. Texas Okla. Kan. Mo. Ark. Neb.	Drs. L.J. Grauke and T.E. Thompson
Area IV	W. Texas N.M. Ariz. Calif.	Drs. L.J. Grauke and T.E. Thompson

Testing is often done cooperatively with growers, state experiment stations, state agricultural extension services, and universities. These NPACTS tests are production tests, and are conducted using the standard cultural and production recommendations for each NPACTS location. Selected individuals are propagated on standard rootstocks in replicated, randomized complete block orchard configurations for intensive testing for 15 years. Selected clones are propagated on standard rootstocks for each NPACTS area and are compared to industry standard cultivars, such as 'Desirable', 'Western Schley', and 'Wichita'. Aspects of production, nut quality, phenology, growth, and insect and disease resistance are systematically evaluated in relation to outstanding cultivars in each region. Trunk diameter, mean previous-season shoot length, canopy width, and tree height are determined during the dormant season. Budbreak and dichogamy are determined to estimate suitability of clones to serve as pollinators for other clones, and to access the probability that they will be well pollinated by clones of opposite dichogamy. Disease damage is rated during the growing season as damage from scab, vein spot, fungal leaf scorch, shuck disease, etc., becomes apparent. Normally, insects are chemically controlled, but genetic differences are rated as the opportunity arises.

Yield determinations are of greatest importance with actual yield for each tree being recorded every year. Date of shuck split is recorded to determine harvest date for each clone. Mean number of nuts per cluster and percent terminals with clusters are determined. Time of leaf drop in the fall is recorded since trees which hold healthy leaves longer are less likely to alternate bear. Methods of evaluation are standardized across locations, with evaluation procedures

being continually refined. Clones which perform well in these NPACTS tests, compared to industry standard cultivars for the area, are released as new cultivars. A new cultivar could possibly be released every 2-5 years. This means that about 10,000-25,000 clones may be screened in the entire breeding program to produce a single new cultivar. This figure seems quite realistic from a genetic standpoint when projected heritabilities of different traits are considered. Table 1 shows the pedigree and other information for the USDA-ARS/state released cultivars.

RELATED RESEARCH

Basic research related to the breeding program consists mainly of techniques to improve breeding efficiency. One of the most direct needs is a technique to induce early flowering in juvenile clones at perhaps 2-3 years of age. Currently, most pecan seedlings flower at 6-7 years of age. We have induced early flowering in pecan on 15 month old clones (time of germination to pistillate flower production). The frequency, however, was very low, and to be useful as a standard breeding technique, the frequency must be greatly increased. Early flowering has been accomplished in some other tree species, but specific techniques to accomplish this in pecan have not been developed. The benefits of such techniques are obvious in selection programs to radically alter gene frequencies which control important traits; such as yield, nut maturity time, and disease and insect resistance.

Pecan is considered by some to be a relatively inefficient food production crop. We feel the main reason for this is its late nut filling period. The pecan kernel begins to form about August 15. This is a period of the year when the days are becoming shorter (less light for photosynthesis), the leaves have been damaged by insects and diseases all season, the roots are competing with the nuts for photosynthate to replenish root carbohydrate reserves for winter and spring growth, and perhaps soil moisture and nutrients have been exhausted by six months of active growth. This heavy masting effect late in the season also induces the absence of flower production the following spring which accentuates the alternate bearing syndrone in pecan. Perhaps this alternate bearing was needed in the wild to escape nut feeding insects, but it is definitely not needed in improved orchards.

The basic consideration here is that the pecan tree is designed wrong for maximum nut production. It is too much a forest tree designed to effectively compete with other species for space in forest canopies. This is mainly related to fast vegetative growth which is needed for competitive survival in the wild, but exactly what is not needed in developed orchards where competition is artificially removed. The idea is to direct more photosynthate into the earlier production of nuts and less into the production of unneeded wood.

We feel late nut development in pecan has resulted from selection induced by animals feeding on the earliest maturing nuts. This effect is obvious in stands of clones, some of which mature early. These nuts are completely destroyed by feeding animals in the area. Clones with nuts maturing later partially escape this severe feeding pattern, and a portion of the nuts are stored underground by squirrels or otherwise allowed to germinate the following Spring. It is interesting that pecan is one of the latest species, as far as developing nuts, in the *Carya* genus. We believe this is the result of animal selection. We would guess that time of filling is largely a quantitative trait, and a few sexual generations will be needed to radically alter it. The importance of a technique to artificially induce early flowering here is obvious.

The nut filling period may also be too short in pecan. Lengthening this period in some other crops has improved yieldability.

The xenia effect or the immediate effect of the pollen on nut filling and development is also being studied. The presence of this effect in species related to pecan has been documented and some studies have been completed on pecan. It seems obvious that pollen source is important in nut development. We need to determine the value of this effect so that specific cultivar recommendations can be made when new orchards are established. We also now know that pollen from some cultivars reduce premature nut sprouting or vivipary. In the past, good pollination meant any viable pollen to effectuate fertilization. We now know that some pollen sources are much more effective in producing more and larger nuts after fertilization.

A need to control or reduce tree size is generally recognized in pecan. There has been some past reference to dwarf varieties that are currently available. For example, 'Cheyenne' is sometimes considered "dwarf-like." This terminology is unfortunate because 'Cheyenne' and some other clones are only slower growing, and are not really dwarf-like at all. Whether tree size can be reduced most effectively by discovering and using dwarfing rootstocks or by developing dwarfed cultivar (scion) clones is debatable. There are advantages to each. In Persian walnut production in California, small tree size results from genetic characteristics of the scion growing on a very vigorous rootstock. This should also work in pecan. In any event, hopefully future cultivars will be partially dwarfed by nut production or the absence of so much photosynthate available for vegetative growth in the Spring when most shoot extension growth occurs.

Heritability studies of different genetic traits are also conducted as a part of the breeding program. This knowledge allows the effectiveness of the breeding program to be improved, by more accurate prediction of how many clones of each cross will be lost due to inadequate yield potential, nut size, disease resistance, etc.

You can see that the USDA-ARS pecan breeding program conducted cooperatively across the entire U.S. production area consists of many varied and interrelated activities by breeders, geneticists, horticulturists, pathologists, and entomologists. It is the largest, and essentially, the only pecan breeding program in the world. To date (and in cooperation with state agricultural experiment stations), 20 improved cultivars have been released. Conservative estimates show that 1/10 of the extra crop value produced by just 'Wichita' is adequate to fund the USDA-ARS Pecan Breeding Program. Public funding of pecan breeding research is obviously an excellent investment in the future well being and nutrition of mankind.

Table 1. Cultivars developed cooperatively by the U.S. Department of Agriculture and state agricultural experiment stations.

Cultivar	Parentage	Selection	Released	Dichogamy
Barton	Moore X Success	37-3-20	1953	I
Comanche	Burkett X Success	37-8-22	1955	II
Choctaw	Success X Mahan	46-15-276	1959	II
Wichita	Halbert X Mahan	40-9-193	1959	II
Apache	Burkett X Schley	40-4-17	1962	II
Sioux	Schley X Carmichael	43-4-6	1962	II
Mohawk	Success X Mahan	46-15-195	1965	II
Caddo	Brooks X Alley	Philema 1175	1968	I
Shawnee	Schley X Barton	49-17-166	1968	II
Cheyenne	Clark X Odom	42-13-2	1970	I
Cherokee	Schley X Evers	48-22-27	1971	I
Chickasaw	Brooks X Evers	44-4-101	1972	II
Shoshoni	Odom X Evers	44-15-59	1972	II
Tejas	Mahan X Risien #1	44-10-293	1973	II
Kiowa	Mahan X Desirable	53-9-191	1976	II
Pawnee	Mohawk X Starking H.G.	63-16-125	1984	I
Houma	Desirable X Curtis	58-4-61	1989	I
Osage	Major X Evers	48-15-3	1989	I
Oconee	Schley X Barton	56-7-72	1989	I
Navaho	48-13-311 X Wichita	74-1-11	1994	I

Average Development time from crossing to release is 25 Years (Choctaw = 13, Caddo = 45).
Parentage: Mahan = 5; Schley = 5; Success = 4; Evers = 4.

BENEFITS OF GOOD ORCHARD FLOOR MANAGEMENT ON THE GROWTH AND PRODUCTION OF YOUNG PECAN TREES IN THE SOUTHEAST

M.G. Patterson[1] and W.D. Goff[2]

ABSTRACT

Pecan, *Carya illinoensis* Wang. K. Koch 'Desirable', trees planted in 1986 and subjected to different orchard floor management regimes both with and without irrigation were measured yearly for growth and yield. Trees receiving total chemical weed control grew larger and cummulatively produced approximately four times as many pecans by the 8th leaf as compared to weed infested trees (4243 vs 1086 kg/ha). Irrigation increased growth in 6 of 8 years but only increased yield in 1 of 4 years in an area of relatively high rainfall. Trees which were weedy for the first 2 or 3 years and then rotated to total chemical weed control or trees which were weedfree for the first 2 or 3 years and then allowed to go weedy produced intermediate yields compared to the extremes of total chemical weed control continuously or no weed control continuously.

INTRODUCTION

Pecan orchard floor management has evolved over the years to arrive at the current sod-strip system used by many growers in the Southeastern U.S. This method calls for a relatively weedfree strip in the tree row and a sod roadway between rows which is maintained for sprayer traffic (Alabama Coop. Ext. Ser. 1993, Worley 1989). The weedfree strip can vary in width the grower wants to invest in weed control. A strip one to two meters on either side of the tree is commonly used. Several heribicides are registered for use in pecan orchards which, when used in combination, can provide complete weed control under pecan trees.

Until recently, the effects of weeds on young pecan tree growth and yield was not known. Research conducted in Alabama over the past 8 years documents the adverse effects of letting weeds, especially grasses, grow uncontrolled around newly planted pecans (Patterson, et al. 1990, Patterson and Goff 1994). Tree growth and yield were decreased significantly if weeds were not controlled around newly planted trees through the 8th leaf and possibly longer. Nutrient deficiencies have been found in pecan leaves from trees which have not received adequate weed control, even though the recommended amounts of fertilizer and lime were applied each year (Goff et al. 1991). Mechanical weed control, i.e. disking, was effective when the trees were irrigated, but inadequate when trees were not irrigated due to the soil drying influence of tillage (Patterson, et al. 1990). Mowing has not been effective since grasses, especially perennial grasses, are not controlled and continue to rob the tree of nutrients and water.

Low growing weeds like bermudagrass, *Cynodon dactylon* (L.) Pers., also influence the growth of young peach, *Prunus persica* L., trees (Weller et al. 1985). Weeds decrease both growth and yield of youngs pecans, but it is not known if weed control must be maintained from planting onward, or if control can be reduced at a point when the trees are well established. Continuing work in Alabama will help answer some of these questions.

METHODS AND MATERIALS

Pecan trees, cultivar Desirable, were planted at the Alabama Agricultural Experiment Station, Fairhope, Alabama in February 1986 and subjected to different weed management and irrigation regimes. Five weed management regimes consisted of 1) 'total' complete weed control with registered herbicides, 2) disking once monthly, 3) mowing twice per month, 4) grass control only with selective herbicides, and 5) none. Weed control treatments were applied to a 3- by 3-m area centered on the tree during the first 5 years of the study. This area was expanded to a 4- by 4-m area starting in 1991. One half the trees in this study were irrigated using five emitters per tree, each emitter delivering 3.8 L per hr, and operated when no rainfall had been received after a 4-day period (Curtis et al. 1986). All combinations of weed management regimes and irrigation (irrigated or not) were represented in a factorial arrangement using a randomized complete block design with four single tree replicates. Weed species infesting the study included bermurdagrass, yellow nutsedge (*Cyperus esculentus* L.), prickly sida (*Sida spinosa* L.), and several other species (Patterson et al. 1990). Herbicides used in obtaining the total chemical and grass control only treatments included oryzalin, norflurazon, fluazifop, simazine, diruon, and glyphosate. Soil fertility, pH, disease and insect control, and pruning were maintained for optimum pecan production.

In the original study design, additional trees were planted and subjected to the above treatments in order to allow rotation of weed management regimes after 2 and 3 yrs. While the basic weed management treatments have been used continuously since planting on one group of trees, additional trees which received the 'total' weed control regime for the first 2 or 3 yrs were rotated to the none (no control) regime. Likewise, trees which received the none

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regime for the first 2 or 3 yrs were rotated to the 'total' weed control regime. These rotational or "flip-flop" treatments were installed to determine if a grower could delay weed control practices for the first 2 or 3 yrs or discontinue weed control after the first 2 or 3 yrs without adverse effects. Irrigation was discontinued after the 1992 growing season, leaving the study with only one irrigation variable. Fairhope receives an average of 175 cm rainfall per year.

Data collected included tree stem diameter 65 cm above ground measured at planting in February 1986 and yearly thereafter and nut production starting in 1990.

RESULTS AND DISCUSSION

Cummulative tree growth during the first 4 yrs of the study was rapid for all treatments (Table 1). Trees receiving orchard floor management regimes of total chemical control or disking grew larger than trees receiving mowing, grass control only, or no control in each year except the year of establishment (Table 1). Mowing was no better than no control as perennial grasses were not killed by this treatment and continued to regrow after mowing. Irrigation increased overall growth in each year except the year of establishment. Within each irrigation regime, total weed control was worth at least one years growth compared to the no weed control trees.

Cummulative tree growth by treatment slowed and equilibrated once trees began bearing in 1990, but the size difference between treatments obtained in the first 4 yrs remained (Table 2). Total weed control with herbicides continued to provide the fastest growth. Irrigation also provided overall increase in tree diameter, even in an area of relatively high rainfall.

Pecan yields were somewhat reflective of tree growth in that larger trees produced more nuts sooner and continued to do so from 1990 through 1992 (Table 3). Under irrigation, trees subjected to total chemical and disking floor management regimes produced yields higher than trees receiving mowing, grass control only, and no control regimes. When not irrigated, yields from disking treatments decreased below yields of total chemical control treatments. Tillage drys the soil, helping to rob the tree of moisture needed for pecan production. Irrigation increased overall yield in 1991 only. Although not analyzed, yield from total chemical treatments were numerically higher than yield from other weed management regimes in 1993 when irrigation was not used.

When averaged over irrigation regimes, pecan yield from "flip-flop" treatments fell inside the extremes of yields produced by total chemical control and no weed control (Figure 1). These treatments will be continued to determine if yield from any delayed weed control treatment will catch up to yield from trees which have received total chemical control continuously.

SUMMARY

Weed control around young pecan trees in the Southeastern U.S. increases growth and nut production. Trees which have received good orchard floor management produce a larger crop earlier. Preliminary data show trees receiving delayed weed control or trees from which weed control was discontinued after the first 2 or 3 years will not produce yields equal to continuous total weed control for several years. At some point in the future the yield from trees which were initially weedy and changed to total control after 2 or 3 yrs may equal yield from trees which have received total weed control continuously. However, the yield loss until that time will probably exceed the costs of weed control inputs required initially.

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Table 1. Pecan diameter as influenced by weed control and irrigation in nonbearing trees, Fairhope, Alabama

Irrigation and weed control program	Year 1987	1988	1989	1990	Total growth increase[a] %
	----------cm----------				
Irrigated Total	2.3 a[b]	4.6 a	6.8 a	9.5 a	400
Disking	2.3 a	4.2 ab	6.3 a	8.9 a	368
Mowing	2.1 ab	3.0 c	4.2 c	6.3 c	232
Grass only	2.1 ab	3.8 b	5.6 b	8.0 b	321
None	2.0 b	2.8 c	4.5 c	6.8 c	258
Mean of irrigated	2.2 A	3.7 A	5.5 A	7.9 A	316
Not irrigated					
Total	2.1 ab	4.0 a	6.3 a	8.9 a	368
Disking	2.2 a	3.9 a	5.6 b	7.8 b	310
Mowing	2.1 ab	2.8 c	4.0 cd	6.0 cd	216
Grass only	2.1 ab	3.4 b	4.7 c	6.9 bc	263
None	2.0 b	2.9 c	3.9 d	5.7 d	200
Mean of not irrigated	2.1 A	3.4 B	4.9 B	7.1 B	271

[a] Cumulative increase between planting in Feb., 1986, at which time the average tree diameter was 1.9 cm, and Feb., 1990.

[b] Means in column followed by the same letter are statistically equivalent according to Duncan's multiple range test at the 5% level of probability.

Table 2. Pecan stem diameter as influenced by weed control and irrigation in bearing trees[1], Fairhope, Alabama

Irrigation and weed control program	Year 1991	1992	1993	Cumulative Growth Increase[2] %
	----------cm----------			
Irrigated				
Total	11.9	14.5	16.4	76
Disking	10.8	12.8	15.2	71
Mowing	8.6	11.1	13.4	113
Grass only	9.4	11.9	13.6	70
None	8.4	11.4	13.1	93
Mean of irrigated	9.8	12.3	14.3	85
Not irrigated				
Total	11.2	13.9	16.0	80
Disking	9.6	12.1	14.5	86
Mowing	7.8	9.7	12.5	108
Grass only	8.2	10.7	13.0	88
None	6.9	8.9	10.6	86
Mean of not irrigated	8.7	11.1	13.3	90
LSD (.05) weed control	1.7	2.2	1.9	
LSD (.05) irrigation	0.8	1.0	0.9	

[1] Tree stem diameter measured in February each year.

[2] Determined from 1990 until Feb. 1993.

Table 3. Pecan yields as influenced by weed control and irrigation[1], Fairhope, Alabama

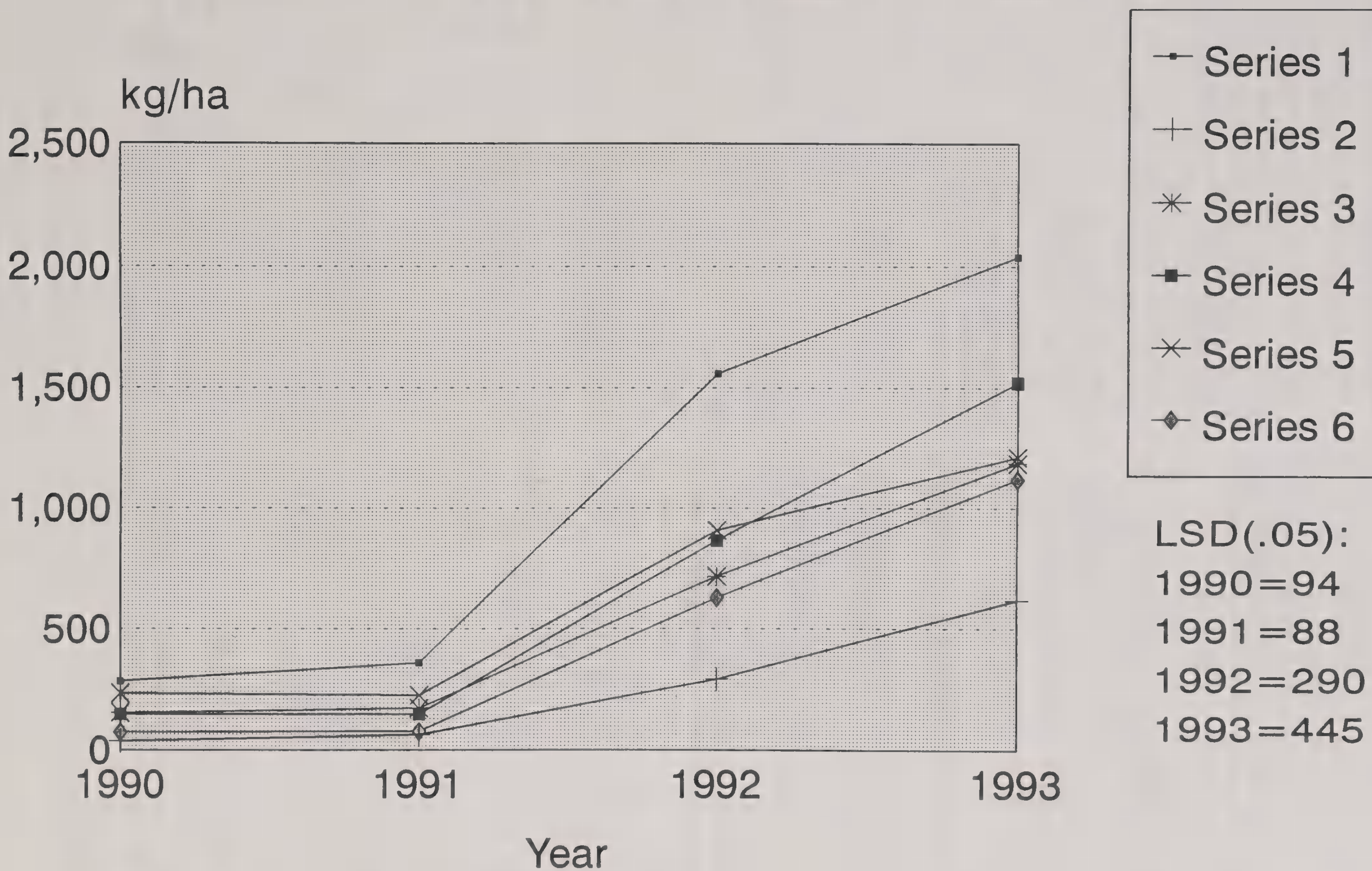
Irrigation and weed control program	1990	1991	1992	1993[2]	Cumulative
	--------kg/ha--------				
Irrigated					
Total	254	436	1628	2072	4390
Disking	262	454	1316	1752	3784
Mowing	11	57	430	1015	1513
Grass only	49	134	545	1068	1796
None	27	86	308	739	1160
Mean of irrigated	121	233	846	—	
Not irrigated					
Total	315	286	1490	2006	4097
Disking	94	162	762	1235	2253
Mowing	53	91	584	853	1581
Grass only	116	75	395	1093	1679
None	49	41	277	644	1011
Mean of not irrigated	125	131	701	—	
LSD (.05) weed control program	143	129	445	—	
LSD (.05) irrigation	NS	56	NS	—	

[1]Yields obtained in November each year.

[2]Irrigation treatments discontinued in 1993.

Pecan Yield from Continuous and Flip-Flop Weed Control

Fairhope, Alabama--Averaged over irrigation variables



Series: 1 = total continuously, 2 = weedy continuously, 3 = total 2yr fb weedy
4 = weedy 2yr fb total, 5 = total 3yr fb weedy, 6 = weedy 3yr fb total

IRRIGATION MANAGEMENT FOR PECANS

L.A. Stein[1]

Even though irrigation of pecans is a fairly recent practice, except in the far west, water is critical for the survival, growth and economic production of quality pecans.

Careful irrigation is needed so that young trees can grow rapidly to a large size. This has been demonstrated in numerous pecan orchards the past 10 years where young trees have been brought into commercial production in 5 to 7 years (McEachern 1993). A critical component of this rapid overall orchard establishment program has been timely water applications.

Mature trees need water at 5 critical periods; initial spring growth, nut sizing, water stage, kernel filling and shuck split. Early in the growing season bearing pecan trees need water to initiate strong, vigorous growth. In May and June water is necessary for nuts to develop to a satisfactory size. Water stage irrigation is needed to prevent nut drop. Late summer irrigations allow full development of the kernels in August and September. This "filling" irrigation is an important factor in determining the quality of the nuts. The final mature tree water requirement is prior to shuck split in October.

The latest research shows that pecans have a high water requirement just before shuck split (Stein et al. 1989). Leaf drop, poor or impaired shuck opening (sticktights) and vivipary can be decreased by irrigating up until the time of shuck split. This may well require a final irrigation by variety.

Irrigation water management must not only assure that a continuous supply of soil moisture is available to the trees, but also that the water be managed to prevent over-irrigation and water-logging. Roots thrive best when the water is present in soil's oxygen supply that the roots must have to survive and absorb nutrients and is just as detrimental to the tree as drought.

SOIL WATER HOLDING CAPACITY

The first step in irrigation water management should be to determine the soil reservoir that is available for supplying the water needs of the trees. This is controlled by the depth of soil aeration and the water holding capacity of each foot depth of soil into which the roots permeate. This reservoir capacity, together with the water use rate of the trees, controls the frequency and depths of water that should be applied at each irrigation.

The depth of available water that can be retained in the soil for use by the trees is controlled by the soil texture, which is the size of the soil particles. The inches depth of available water that can be stored in each foot depth of soil will vary from 1/2 to 1 inch in sands, 1 to 1-1/2 inches in sandy loams, and 2 to 2-1/2 inches in clays. Consequently, different soil types will hold different amounts of water.

For instance, the upper foot of the Demona series of soils will hold 1.2 inches, whereas, the upper foot of the Hasse series will hold 2.4 inches of available water. Hence, certain soils can have more water available to the trees than other soils. Soil's water holding capacities are generally available at the local soil conservation office.

WATER ABSORPTION

Pecan trees normally extract most of the water they use from the upper 36 inches of the soil profile, even though they are deep rooted plants. They can extract water from deeper profiles; however, they must expend more energy to pull water up from deeper strata.

The deeper the water, the more energy is diverted away from the developing leaves and nuts. The tree compensates by shedding leaves, part of the crop load or only moderately filling the pecans. Prior to shell hardening, nuts are shed, whereas after shell hardening leaves are shed.

Realistically speaking, from the standpoint of irrigation and water use, deep water is survival water and does little to contribute to orchard profitability.

WATER REQUIREMENTS

For the majority of the pecan belt, irrigation is applied on a supplemental basis. Pecans are reported to require about 55 inches of water a year (Miyamota 1983). Some estimates as low as 30 inches have been published (McEachern 1982), and some growers report benefits from amounts as high as 72 inches. Water may fall as rain in some areas, but rainfall is rarely distributed appropriately through the growing season to meet plant needs. Thus, irrigation water is supplied to supplement natural rainfall.

In order to plan irrigation systems, it is necessary to know how much water is required by trees; considering both rain and irrigation water.

A well-accepted value for figuring the water use of mature pecans is 55 acre inches per year. It is safe to say that most of that water will be used during the growing season (225

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days). This being the case, daily water use can be predicted as follows:

55 acre inches per year x 27,154 gallons per acre inch = 1,493,470 gallons per acre, per year

1,493,470 gallons/225 days = 6,638 gallons/acre/day\

6,638 gallons/35 trees per acre = 190 gallons per tree, per day

The standard Texas Agricultural Extension Service recommendation of 1 to 2 inches per week can be calculated into daily water requirements in much the same way:

1 acre inch x 27,154 gallons per acre inch/7 days = 3,879 gallons/acre/day

3,879 gallons per day/35 trees per acre = 111 gallons per tree, per day

Two inches per week computed is twice the amount above or 222 gallons per tree, per day.

Both of these systems generate very plausible numbers for daily pecan water use.

Using a third system, the pecan tree water requirements can be based on the area of a tree's canopy and the evaporation of water from a U.S. Weather Bureau Class "A" Pan. This works well because the same forces that affect evaporation from a tree's leaves operate on an open body of water.

Dr. J.W. Worthington at the TAMU Center at Stephenville has shown with lysimeters, that young pecan trees use water at a rate that is proportional to the water evaporating from a Class "A" Pan (Worthington et al. 1988). In May and September, pecans use about half (50 percent) as much water as evaporates from the pan. In June 80 percent, August 90 percent, and in July pecans use 100 percent of pan evaporation. Based on our data (Stein et al. 1989), mature trees with a heavy crop probably use water at 100% in July, August, September and even part of October.

Water use in pecan trees is controlled by the leaves, hence larger trees (with more leaves) will use more water. The following formula is used to determine the exact pecan tree water requirements: Water use = pan evaporation (inches) percent appropriate to month x the area covered by the tree's canopy (acres).

If we assume a mature orchard (planted 35 x 35) has trees with canopies 20 feet in diameter, and July pan evaporation of .44 inches, the following calculations can be used to determine tree water use in gallons per tree. There are 27,154 gallons of water in an acre inch. If the pan evaporation = .44 acre inches, .44 x 27,154 gallons/acre inch = 11,047.8 gallons. The area of the pecan trees is computed as if they were a circle, _ x r^2. Trees with 20 feet diameters have a 10' radius. Hence 10' x 10' x 3.1416 = 317 ft^2 per tree. Dividing 314/43,560 ft^2/acre = .0072 acres. The final step is to multiply .0072 acres x 11,947.8 gallons/acre = 86 gallons per tree per day. Worthington has developed a computer program to make these calculations, simplifying the process.

The most practical way to predict water use is by location pan evaporation. Most weather stations record pan evaporation and as demand for this information increases, it should become more accessible.

Tables have been developed to help growers design their irrigation systems in Texas. These tables are published in the Texas Pecan Handbook.

SCHEDULING IRRIGATION

Pecan irrigation is designed to relieve water stress, and water needs to be applied often enough to meet this goal. This is relatively simple for young trees because the root and top is smaller.

During the first year after transplanting, most of the new root growth is at the cut surface of the tap root and/or large root laterals, with little new lateral root development. Trees can absorb some water through the old roots, but most of the water uptake is from these new, developing roots, that develop at the new cut surfaces made when the tree was planted. Thus, daily watering would tend to saturate the soil near the surface where absorption is limited. For new trees, it is better to apply water once a week.

Seven gallons of water applied once a week will give the tree 1 gallon per day for sustenance and allows ample time for air to re-enter the soil spaces encouraging more root growth. Continue weekly watering for the first 2 years, according to Table 1 if the trees are making good growth.

By the third year, watering by canopy size formulas will be more accurate and better meet the trees' needs.

Irrigation frequency of bearing size pecan trees is often determined by cost, water availability, type system employed, soil type and depth, crop value and weed control practices.

However, the most common methods of scheduling irrigation are as follows: feeling the soil 6 to 12 inches below the surface; by the calendar; tensiometers; gypsum blocks; water mark sensors; neutron probe; infra-red gun; indicator plants; by season or drought; and when one can obtain water or get to it. All methods have pluses and minuses, but all have different variations that are modified by growers. In fact, there are as many different irrigation scheduling techniques as there are growers.

Although the best irrigation schedule for a grower is one that works for his or her situation, a good irrigation scheduling program would give consideration to the following practices:

First, the water holding capacity would be determined in the top 36 inches of the orchard soil. Based on tree canopy size and pan evaporation data, the trees' daily water use values are known. Water use is then subtracted from the available water and irrigation is applied prior to depletion.

This system works well on irrigation systems, such as flood or sprinkler, that wet the entire orchard floor or at least large volumes of soil. In this way, enough water is placed in the top 36 inches of the soil to meet the trees' needs. Generally, high frequency irrigation systems only wet a small portion of soil.

Also, prior to spring growth, make sure that the soil has been wetted to the full depth of rooting of the trees. If winter rainfall has not replenished the soil moisture to this depth, a late winter or early spring irrigation should be applied.

High-frequency irrigation systems such as drip or microsprinkler are generally designed to supply the trees' daily water requirement, hence many operate every day. The amount of soil wetted would generally determine frequency of application. The trick is to keep the water in the top 36 inches of the soil profile.

Tensiometers, gypsum blocks, neutron probes and devices that measure the water status of the trees should be used to check irrigation performance. Such devices are often used to schedule irrigation.

However, a good system for scheduling irrigation is simply feeling the soil as outlined in Table 2. Although not a precise or scientific method, it can be extremely effective if the results are observed carefully.

Depth of water penetration into the soil should also be determined. A soil probe, sharpshooter or one of the soil moisture measuring devices can be used. Water should have penetrated 3 feet after the irrigation. If penetration depth is more or less than 3 feet, the irrigation schedule or amount of water applied should be adjusted.

Regardless of system used, one must correlate soil condition with the instrumentation used. If the soil feels wet then the device should also indicate such. If not, one must make adjustments for the inaccuracy. The key is to know what is happening before and after irrigation.

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Table 1. General water rate guide for pecans on well-drained soil

	Volume per week (gallons) Tree						
Age	April	May	June	July	August	Sept.	October
1	7	7	14	28	28	14	7[1]
2	14	14	28	56	56	28	14

[1] If extremely dry

Table 2. Soil moisture values based on feel[1]

Moisture sensor reading	Soil Type			Amount of irrigation water to apply
(Bars)	Coarse	Light	Medium	
0	Free water appears when soil is bounced in hand	Free water released with kneading	Can squeeze out free water	System off
0.2				25% of required
0.3	Wet outline of ball is left on hand upon squeezing	Same as coarse	Same as coarse	50% of required
0.35				75% of required
0.4	Tends to stick together forms a weak ball under pressure	Forms weak ball, breaks easily will not stick	Forms ball, very pliable, sticks readily if high in clay	100% of required

[1] Table adapted from USDA 1955 Yearbook of Agriculture

LIGHT PRECONDITIONS AND FLUCTUATING IRRADIANCE LEVELS INFLUENCE GAS EXCHANGE OF PECAN LEAVES

P.C. Andersen[1] and B.V. Brodbeck[1]

Additional Key Words: *Carya illinoensis*, intercellular CO_2 concentration, net CO_2 assimilation, stomatal conductance, transpiration, water use efficiency.

ABSTRACT

The influence of light preconditions and fluctuating irradiance levels was investigated on leaf gas exchange characteristics of pecan [*Carya illinoensis* (Wagenh.) C. Koch] leaves. Pecan leaves shaded with polyethylene shadecloth (neutral filter; 30% light transmittance) for 14 days had greatly reduced rates of CO_2 and H_2O exchange. Light response curves for leaves of sun- and shade-preconditioned (compiled 1 to 4 hr after shadecloth removal) indicated that sun-preconditioned leaves had a higher net CO_2 assimilation rate (A) at photosynthetic photon flux (PPF) >200 μmol m^{-2} s^{-1}, although apparent quantum yields (at PPF <150 μmol m^{-2} s^{-1}) were not altered. Light compensation points occurred at a PPF of 84 and 69 μmol m^{-2} s^{-1}, and dark respiration rates were 2.6 and 1.7 μmol m^{-2} s^{-1} for sun- and shade-precondi-tioned leaves, respectively. Light saturation (calculated as 95% A_{max}) occurred at a PPF of ca. 1500 and 1300 μmol m^{-2} s^{-1}, for sun- and shade-preconditioned leaves, respectively.

When leaves were exposed to short-term (80 to 240 sec) reductions in irradiance, A declined rapidly, yet stomatal conductance to water vapor (g_s) was not significantly altered. At low levels of irradiance water use efficiency (WUE) was near 0 and intercellular CO_2 concentration (Ci) was near ambient levels. Gas exchange of leaves was in direct response to the leaf or leaflet microenvironment; altering the light status of adjacent leaves or removing adjacent leaves did not influence gas exchange. In conclusion: 1) shading trees greatly reduced rates of leaf gas exchange; 2) light preconditions modified leaf gas exchange upon reexposure to full sunlight; 3) g_s of pecan leaves was independent to short-term fluctuations in irradiance levels (i.e., A and g_s were not tightly coupled), and; 4) short-term light acclimatization occurred on an individual leaf or leaflet basis.

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INTRODUCTION

Previous environmental conditions influence plant response to current environmental stimuli. Leaves undergo physiological and anatomical adaptations in response to changes in irradiance. Gas exchange characteristics of sun- and shade-grown leaves differ in that shade-grown leaves have higher quantum yields, but lower dark respiration rates, light saturation points, maximum rates of net CO_2 assimilation and net CO_2 assimilation rate per unit chlorophyll (Anderson and Osmond 1987, Bjorkman 1981, Kappel and Flore 1983, Lee et al. 1990, Syvertsen 1984).

Although rates of pecan leaf gas exchange in full sunlight are high for a C_3 plant (Andersen and Brodbeck 1988), little information exists concerning the influence of fluctuations in irradiance and of light preconditions on leaf gas exchange characteristics of pecan. Also, the influence of light on adjacent parts of the canopy on leaf gas exchange characteristics is not known. Understanding the effects of preconditioning and fluctuating irradiance may be particularly critical to pecans in the Southeast where intermittent, variable cloud cover is a normal climatic condition. This information would increase our knowledge of whole tree carbon gain under field conditions.

The influence of light intensity on carbon assimilation has been researched extensively with the majority of experiments performed under controlled conditions in the laboratory. Although providing useful physiologic information, these data often are difficult to relate to field conditions. In nature, plants are exposed to fluctuations in irradiance throughout the day, and steady rates of leaf gas exchange are seldom achieved (Norman and Turner 1969, Knapp and Smith 1988, 1989, 1990). Intermittent cloud cover (which can reduce light levels to ca. 10 to 30% of full sunlight), wind-generated leaf movements and mutual shading among canopy leaves may result in changes in irradiance lasting less than a second to hours.

Net CO_2 assimilation declines quickly with the onset of shade and increases rapidly with the occurrence of unobstructed sunlight. The stomatal response to fluctuating irradiance, however, varies widely among species (Chazdon and Pearcy 1986, Knapp and Smith 1988, 1989, 1990, Pearcy 1988). Leaf stomata of many herbaceous plants or shrubs often have a strong "tracking" response to fluctuating irradiance levels, whereas stomatal conductance (g_s) of leaves of mesophytic tree species is often independent of short-term changes in irradiance levels (Andersen 1991, Knapp and Smith 1990). Information concerning tracking/non-tracking stomatal responses of horticultural crops to fluctuating irradiance levels is limited.

The objectives of this study were to investigate the influence of: 1) light preconditioning; 2) fluctuations in irradiance; and 3) the light environment of adjacent limbs, leaves and leaflets on gas exchange characteristics of pecan leaves.

MATERIALS AND METHODS

Plant material. Studies were conducted on 'Cape Fear' (3rd to 4th leaf) and 'Stuart' (6th leaf) pecan trees at the Agricultural Research and Education Center, Monticello, Florida (30.5N latitude, 84W longitude). Trees were supplied with 96 liters of water daily via drip irrigation. Management procedures were standard. Soil type was a Dothan loamy sand (Plinthic paleudults).

Leaf gas exchange. Ambient and leaf chamber CO_2 and H_2O vapor concentration, air temperature and photosynthetic photon flux (PPF) were measured in the field with an Analytical Development Corporation (ADC) Model LCA-2 infrared gas analyzer, an air supply unit, and a Parkinson broadleaf leaf chamber (Analytical Development Corp Ltd., Hoddesdon, Herts., England) as described previously (Andersen and Brodbeck 1988) with modifications. Boundary layer conductance and a CO_2 correction factor arising from water vapor dilution were estimated according to Parkinson (1984) and von Caemmerer and Farquhar (1981), respectively. Calculations of net CO_2 assimilation rate (A), stomatal conductance to water vapor (g_s), vapor pressure deficit (VPD), leaf temperature (LT), transpiration (E) and intercellular CO_2 concentration (Ci) were accomplished with an ADC DL 2 Datalogger and software. Leaf gas exchange was measured on recently expanded leaflets from 1000 to 1400 HR unless otherwise specified. Individual measurements of leaf gas exchange were accomplished under ambient condition of light, temperature and humidity (i.e., range of values indicated in Fig. and Table legends). The time required for individual measurements of leaf gas exchange was 60 to 90 sec. Gas exchange was essentially limited to the abaxial leaf surfaces.

Diurnal leaf gas exchange characteristics after long term exposure to 30% full sunlight. On 18 Apr 1990, four 'Cape Fear' trees were completely covered with polyethylene shadecloth (30% light transmittance). After 2 weeks, gas exchange was determined on fully expanded leaves of four replicated shade-exposed and sun-exposed (control) trees every 2 hr from 800 to 2000 HR as described above. Values of A, g_s, E, WUE and Ci are reported as mean $\pm$1SE for each time interval.

Light response curves of trees preconditioned to 100% and 30% full sunlight. Fifteen days after treatment initiation (on 900 HR on 3 May) shadecloth was removed from four 'Cape Fear' trees, and trees were exposed to full sunlight for 1 hr. Light response curves were compiled for leaves of sun- and shade-preconditioned trees from 1000 to 1400 HR. Photosynthetic photon flux was altered from 0 to 2000 μmol m^{-2} s^{-1} by placing polyethylene shadecloth of varying light transmittance over the leaf. Steady state rates of A were achieved in 1 to 2 min. The relationship of A to PPF was analyzed by linear and non linear regression procedures (Eisensmith 1987). Dark respiration rates and light compensation points were calculated from regression equations at PPF = O μmol m^{-2} s^{-1} and A = O μmol m^{-2} s^{-1}, respectively. Apparent quantum yields were determined from the slope of A/PPF at PPF < 150 μmol m^{-2} s^{-1}, and light saturation points were estimated when values of A reached 95% A_{max}.

Influence of short-term fluctuations in irradiance. Gas exchange was measured on 11 June 1988, on 'Stuart' leaves exposed to fluctuations in irradiance in the following sequence: 100, 66, 33, 10 and 100% sun with each measurement sequence lasting ca. 80 sec. Different levels of PPF were achieved by placing polyethylene shadecloth of varying light transmittance over the leaf chamber with the leaf remaining in the chamber for the entire measurement sequence. Preliminary experiments of continuous measurements on leaves in 100% sun showed that gas exchange of leaves in the chamber was not altered for at least 10 min. Leaf gas exchange was also measured on interior canopy leaves (naturally shaded) under ambient levels of PPF (ca. 483 $\pm$ 21 μmol m^{-2} s^{-1}). Each measurement was replicated ten times (10 trees). Means $\pm$1SE are presented.

Influence of moderate-term fluctuations in irradiance. The effects of moderate durations of shading were tested on 'Stuart' leaves from 1000 to 1200 HR on 12 June 1988. Gas exchange was measured periodically on sun-exposed leaves for 20 min, then for 50 min after polyethylene shadecloth (30% light transmittance) was placed over the leaf. Shadecloth was then removed and measurements were continued in 100% sun for 50 min. Leaf gas exchange was determined by inserting a leaflet from each of four replicate trees into the leaf chamber every 4 to 6 min. Values of A, g_s and Ci were grouped as subsamples for each time interval. Means $\pm$1SE are reported.

Influence of light preconditioning on plant response to short-term fluctuations in irradiance. Leaf gas exchange of sun- and shade-preconditioned 'Cape Fear' trees were measured in reference to short-term fluctuations in irradiance. Shade-preconditioned trees were covered with shadecloth (10% light transmittance) for 7 days preceding measurements. Leaf gas exchange was measured for sun- and shade-preconditioned trees in both sun and shade. The first measurement of all treatments was taken in 100% sun and then three subsequent measurements on the same leaf were taken in sun or shade (i.e., shade resulted by the use of polyethylene shadecoth 10% light transmittance), with each measurement sequence lasting 80 sec. The leaf remained in the leaf chamber for the entire measurement sequence (ca. 5 min). Thus, pretreatments and treatments were as follows: sun/sun, sun/shade, shade/sun and shade/shade. Each measurement sequence was replicated five times. Means $\pm$1SE are reported.

Influence of irradiance levels of adjacent leaves. Four 'Cape Fear' trees or portions of trees were covered with polyethylene shadecloth (10% light transmittance) on 23 June 1988, to test for any possible effects of adjacent leaves. Treatments were as follows: 1) entire tree shaded (10% sun) with one limb remaining sun exposed; 2) limb shaded with one leaf remaining sun exposed; and 3) leaf shaded with one leaflet remaining sun exposed.

Plant responses were tested by comparing gas exchange of sun-exposed and shaded leaflets from a treated limb, leaf or leaflet, and control (sun-exposed from a non treated limb or leaf) of four trees 6 days after treatment imposition. The quantum efficiency (Q) was calculated as:

$$Q = \text{mol } CO_2 \text{ uptake/mol photon}$$

Values of A, Q, g_s, E, WUE and Ci are reported as mean $\pm$ 1SE.

RESULTS

Diurnal leaf gas exchange characteristics after long-term exposure to 30% full sunlight. Carbon dioxide and H_2O vapor exchange rates of pecan leaves on trees exposed to 14 days of 30% sunlight were depressed throughout the day (Fig. 1). Maximum PPF recorded in the 100 and 30% sunlight treatments were ca. 1900 and 600 μmol m^{-2} s^{-1}, respectively. Maximum A of leaves in the 100 and 30% sunlight treatment was 15 and 5 μmol m^{-2} s^{-1}, respectively. The greatest differences in A, g_s and WUE were recorded in the morning; differences had diminished after midday due to reductions in A and g_s in 100% sun. Proportionally, there was a greater reduction in A compared to g_s with shading; consequently WUE declined and Ci increased for shaded leaves.

Light response curves of trees preconditioned at 100 and 30% full sunlight. Light response curves of pecan leaves preconditioned to 100 and 30% sunlight were similar at low PPF and began to diverge at ca. 200 μmol m^{-2} s^{-1} with higher A for leaves of sun-preconditioned trees (Fig. 2). Light saturation of leaves of sun-preconditioned trees (denoted by the PPF at 95% A_{max}) was ca. 1500 _mol m^{-2} s^{-1}; light saturation of shade- preconditioned trees occurred at a PPF = 1300 _mol m^{-2} s^{-1}. Apparent quantum yield (i.e. the slope of A/PPF at PPF < 150 μmol m^{-2} s^{-1}) was not influenced by light preconditions. Light compensation points were 84 and 69 μmol m^{-2} s^{-1}, and dark respiration rates were 2.6 and 1.7 μmol m^{-2} s^{-1} for leaves preconditioned to 100 and 30% sun, respectively.

Influence of short-term fluctuations in irradiance. Stepwise alterations in light intensity, in the sequence 100, 66, 33, 10 and 100% sun, greatly influenced CO_2 uptake, while g_s and E remained essentially constant and E varied slightly (Fig. 3). Consequently, A and WUE were much lower, and Ci was higher at reduced levels of irradiance. Net CO_2 assimilation and WUE were near zero in 10% sunlight (PPF ca. 200 μmol m^{-2} s^{-1}), and Ci was near ambient CO_2 concentration. (Leaf temperature was ca. 1.6° C higher in 100% than in 10% sunlight and was not likely a major contributing factor). Net CO_2 assimilation, WUE and Ci quickly returned to initial rates when leaves were re-exposed to 100% sunlight. Net CO_2 assimilation was also reduced more than g_s or E in leaves exposed to prolonged shade in the canopy interior (ca. 23% sun, PPF = 474 μmol m^{-2} s^{-1}); hence WUE was less and Ci was higher in shaded interior leaves compared to sun-exposed exterior leaves.

Influence of moderate-term fluctuations in irradiance. Net CO_2 assimilation, g_s and Ci were stable for 20 min when exposed to 100% sun (Fig. 4). Shortly after the onset of 30% sunlight, A was reduced, g_s declined slightly and Ci increased. After 50 min of exposure to 30% sunlight (i.e., 70 min after initial measurements) A remained stable at 50% of initial values and g_s and Ci declined gradually. With a return to full sunlight gradual increases in A and g_s, and decreases in Ci occurred. However, increases in LT and VPD occurred after a return to 100% sun.

Influence of light preconditioning on leaf response to short-term fluctuations in irradiance. Net CO_2 assimilation of sun-preconditioned leaves exposed to 320 sec of full sun remained at ca. 15 μmol m^{-2} s^{-1}, while A of shade-preconditioned leaves increased after 80 sec and stabilized at ca. 10 μmol m^{-2} s^{-1} (Fig 5a). Transpiration, WUE and g_s remained stable for both sun- and shade-preconditioned leaves, although values of E, WUE and g_s were consistently higher for sun- than for shade-preconditioned leaves. Net CO_2 assimilation declined more for sun- than shade-preconditioned leaves when irradiance changed from 100 to 10% sunlight (Fig. 5b). Stomatal conductance remained higher in sun- than shade-preconditioned leaves throughout the shade cycle. Intercellular CO_2 concentration was similar in sun- and shade-preconditioned leaves in 100% sunlight (Fig. 5a), but with the exposure to 10% sunlight, Ci of sun-preconditioned leaves was higher (Fig. 5b).

Influence of irradiance levels of adjacent leaves. Shading adjacent leaflets, leaves or limbs did not influence leaf gas exchange (Table 1). For example, sun-exposed leaflets manifested similar A and Q whether adjacent leaflets on a leaf were shaded, or adjacent leaves on a limb were shaded, or the remaining leaves of an entire tree were shaded. Similarly, when all leaflets on a leaf or a limb were removed except the measurement leaf, values of A, Q, E, WUE, g_s and Ci were not different from that measured on sun-exposed leaflets from other parts of the tree (data not shown). The one exception was for shaded leaflets when the remainder of the tree was full sun-exposed (Table 1). In this case CO_2 and H_2O vapor exchange were somewhat lower than for other shaded leaflets.

DISCUSSION

In the southeastern United States only a small fraction of solar radiation reaching the stratosphere is incident on the earth's surface due to high humidity and to the prevelance of cloud cover. For pecan trees, maximum potential solar radiation is also reduced by orchard overcrowding or to that proportion of solar radiation intercepted by the upper canopy. The extent to which tree physiology and tree performance may be limited by a lack of solar radiation has not been adequately addressed.

Shading pecan trees for 14 days with shadecloth (30% full sunlight) greatly reduced rates of CO_2 and H_2O vapor exchange throughout the day (Fig. 1). A maximum PPF of 600 μmol m^{-2} s^{-1} (i.e., about 30 to 35% full sunlight) incident on the leaf surface of shaded leaves was associated with a ca. 60 to 70% reduction in A and a 50% reduction in E compared to full sun leaves; hence, WUE was higher for sun-exposed leaves. Stomatal conductance of shade-exposed leaves was substantially reduced during the morning. After 1200 hr a VPD of 4 kPa may have induced partial stomatal closure and may be responsible for the more similar g_s between treatments after 1200 hr. Since A was generally reduced more than g_s with shading, calculated values of Ci were higher in shade exposed leaves. The accuracy of infra red gas calculations of Ci is contingent on relatively homogeneous stomatal aperatures due to the curvilinear relationship between A and g_s (Mansfield et al. 1990). Although there is no evidence that long term shading induces heterogeneous stomatal closure, Ci data must be viewed with caution until confirmation of stomatal homogeneity.

Physiological adaptations to shading such as reduced dark respiration rates, light compensation and light saturation points (Anderson and Osmond 1987, Bazzaz and Carlson 1982, Bjorkman 1981, Syvertsen 1984) occurred for pecan leaves shaded for 14 days (Fig. 2). The 30% decline in A_{max} at high PPF (i.e., 1600 to 2000 μmol m^{-2} s^{-1}) for shade-preconditioned leaves caused by canopy shading indicates that prolonged periods of shading whether caused by cloud cover or by adjacent parts of the tree canopy may be associated with a delay in achieving maximum A or g_s after the return of full sunlight.

Although intermittent cloud cover invariably has a rapid effect on A, the g_s of some plant species respond rapidly to variations in sunlight (henceforth referred to as sun-tracking) while other species maintain a relatively constant stomatal aperture to short-term variations in irradiance levels (henceforth referred to as (non-sun-tracking) (Mooney et al. 1983, Knapp and Smith 1987, 1988, 1989, 1990). Tracking responses may be modified by plant moisture status with a tracking response more prevalent under increased plant moisture stress (Knapp and Smith 1988, 1989, 1990). Our data indicate that pecan with adequate soil moisture is a non-sun tracking species. Stomatal conductance of pecan leaves was lower in shade than in full sunlight (Fig. 2) indicating that the lack of stomatal closure during short-term (Figs. 3, 5) and moderate-term (Fig. 4) reductions in irradiance was due to slow stomatal adjustments, and not because g_s was at maximum values at low levels of PPF (Fig. 1).

Short-term fluctuations in irradiance greatly affected A, WUE and Ci, yet had virtually no influence on g_s or E (Figs 1, 5b). Stomatal opening with exposure to light has been shown to be more rapid than closure during decreasing PPF for a wide range of species (Ceulemans et al. 1989, Woods and Turner 1971). Woods and Turner (1971) showed that steady state g_s of 5 tree species was achieved 12 to 36 min after the onset of shade. Although steady state A of pecan leaves occurred shortly after the onset of shade, g_s and Ci continued to decline after 50 min (Fig. 2). The failure of A and g_s to return to initial levels may be due to the existence of an induction period required to achieve maximum g_s, which for some species may be 25 to 40 min after continuous shading (Chazdon and Pearcy 1986). Alternatively, it may be due to the effects of increasing VPD (Turner et al. 1984). For the first 50 min after the onset of shade, VPD were stable (VPD = 2.1 $\pm$ 1 kPa), but VPD increased markedly after re-exposure to full sun (VPD = 3.1 $\pm$ 0.1 kPa) (Fig. 2). Our other experiments (with the exception of data presented in Fig. 5b) were conducted under fairly similar leaf temperatures and vapor pressure deficits in sun and shade.

A consequence of a non-tracking response of stomata to intermittent cloud cover is a great reduction in WUE. A potential disadvantage of a non-sun-tracking response is a more rapid depletion of soil water which may eventually result in plant moisture stress. Conversely, assuming adequate soil moisture levels, a non-tracking response maximizes carbon gain during the period of reduced irradiance and after a return of full sunlight. The low WUE occurring in interior canopy leaves is compounded by the fact that older leaves which are often located in the canopy interior gradually become insensitive (i.e., do not close) in response to a reduction in water potential (Andersen and Brodbeck 1988). Thus, it appears that for pecan, carbon gain is maximized at the expense of increased water loss.

Shade-preconditioned leaves retained non-sun tracking characteristics, yet the relative decline in A with a reduction in irradiance was less for shade- than for sun-preconditioned leaves. Net CO_2 assimilation and WUE were higher for sun- preconditioned leaves in full sunlight, while A and WUE were higher for shade-preconditioned plants at low PPF in intermittent shade (Fig. 5b).

Disproportionate reductions in A compared to g_s in leaves exposed to short-term reductions in irradiance (Figs. 3, 5b), in naturally-shaded leaves located in the canopy interior

(Fig. 3), and in leaves after 50 min exposure to 30% sun (Fig. 4), resulted in a 30 to 60 µmol mol^{-1} increase in Ci. Similar increases in Ci have been reported in leaves of *Helianthella quinquenervis* and *Senecio triangularis* exposed to simulated cloud cover (Knapp and Smith 1988). Thus, photochemical reactions in the chloroplast responded rapidly to changes in irradiance compared to turgor-mediated guard cell adjustments (Nobel 1983). While anatomical, physiological, and biochemical mechanisms involved in shade acclimation of pecan are complex and poorly understood, feedback inhibition from adjacent leaves did not play a major role in acclimation (Table 1). The lack of an adjacent leaf effect would facilitate acclimation based on the light microclimate of each individual leaf or leaflet.

The responses of pecan leaves to shading are at variance with the strong positive correlations between A and g_s (i.e., constant Ci) that have been reported for many herbaceous species (Dubbe et al. 1978, Farquhar et al. 1978, Wong et al. 1985a, 1985b, 1985c). In contrast, Ci has been altered in leaves as a function of nutrition in peach (*Prunus persica* (L.) Batsch) (DeJong 1982); ABA treatment in grapevine (*Vitis vinifera* L.) (Downton et al. 1987), VPD, leaf temperature and PPF in olive (*Olea europaea* L.) (Bongi et al. 1987) and blueberry (*Vaccinium* spp.) (Moon et al. 1987). Although Downton et al. (1988) showed that patchy stomatal closure (as a result of an exogenous ABA application) may result in erroneous calculations of Ci, they confirmed from fluorescence data that Ci was more variable than previously assumed (Downton et al. 1988).

In conclusion, long term shade induced physiological adaptations of pecan leaves such as reductions in dark respiration rate, and light compensation and light saturation points. Nevertheless, since A_{max} for pecan is achieved at a PPF = 1500 µmol m^{-2} s^{-1} shading reduced carbon assimilation. Net CO_2 and g_s were not strongly coupled in pecan leaves in response to fluctuations in irradiance. A consequence of the weak coupling between A and g_s in pecan leaves is to maximize carbon gain at the expense of increased water loss. Moreover, the gas exchange of leaves (or leaflets) appear to be regulated by microclimate independently, and the status of adjacent leaves exerted little or no influence.

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Table 1. Influence of 6 days of shade pretreatment on gas exchange of 'Cape Fear' pecan leaves. Sun- and shade-exposed leaves were measured at a photosyntheti photon flux of 1502 ± 71 and 492 ± 54 μmol m^{-2} s^{-1}, a leaf temperature of 29.5 ± 0.2 and 29.3 ± 0.3C and a vapor pressure deficit of 2.6 ± 0.1 and 2.8 ± 0.1 kPa, respectively.

		Variable					
		A	Q	E	WUE	g_s	Ci
Pretreatment	Treatment	(μmol m^{-2} s^{-1})	(mol CO_2 mol $photon^{-1}$)	(mmol m^{-2} s^{-1})	(mmol CO_2 mol H_20^{-1})	(mmol m^{-2} s^{-1})	(μmol mol^{-1})
Leaf shaded; leaflet sun-exposed	Control leaflet	14.0 ± 0.9[y]	0.0088 ± 0.0003	7.88 ± 0.35	1.78 ± 0.06	364 ± 26	220 ± 3
	Sun-exposed leaflet	14.1 ± 0.6	0.0085 ± 0.0006	8.25 ± 0.06	1.71 ± 0.07	386 ± 31	225 ± 2
	Shaded leaflet	3.1 ± 0.3	0.0100 ± 0.0016	5.15 ± 0.18	0.59 ± 0.05	181 ± 8	290 ± 5
Limb shaded; leaf sun-exposed	Control leaflet	14.8 ± 0.5	0.0088 ± 0.0005	8.43 ± 0.43	1.76 ± 0.06	414 ± 21	222 ± 2
	Sun-exposed leaflet	14.3 ± 0.3	0.0084 ± 0.0003	8.38 ± 0.18	1.71 ± 0.06	419 ± 17	227 ± 4
	Shaded leaflet	5.8 ± 1.0	0.0098 ± 0.0001	6.65 ± 0.29	0.86 ± 0.12	307 ± 40	281 ± 5
Tree shaded; limb sun-exposed	Sun-exposed leaflet	13.9 ± 0.7	0.0088 ± 0.0005	7.65 ± 0.22	1.81 ± 0.05	385 ± 26	226 ± 3
	Shaded leaflet	5.5 ± 0.7	0.0113 ± 0.0013	6.05 ± 0.42	0.92 ± 0.12	281 ± 39	278 ± 8

[z] Abbreviations: A = net $C0_2$ assimiliation rate; Q = apparent quantum yield; E = transpiration rate; WUE = water use efficiency; g_s = leaf conductance to water vapor; Ci = intercellular $C0_2$ concentration.

[y] Values are mean ± 1 SE, n = 5.

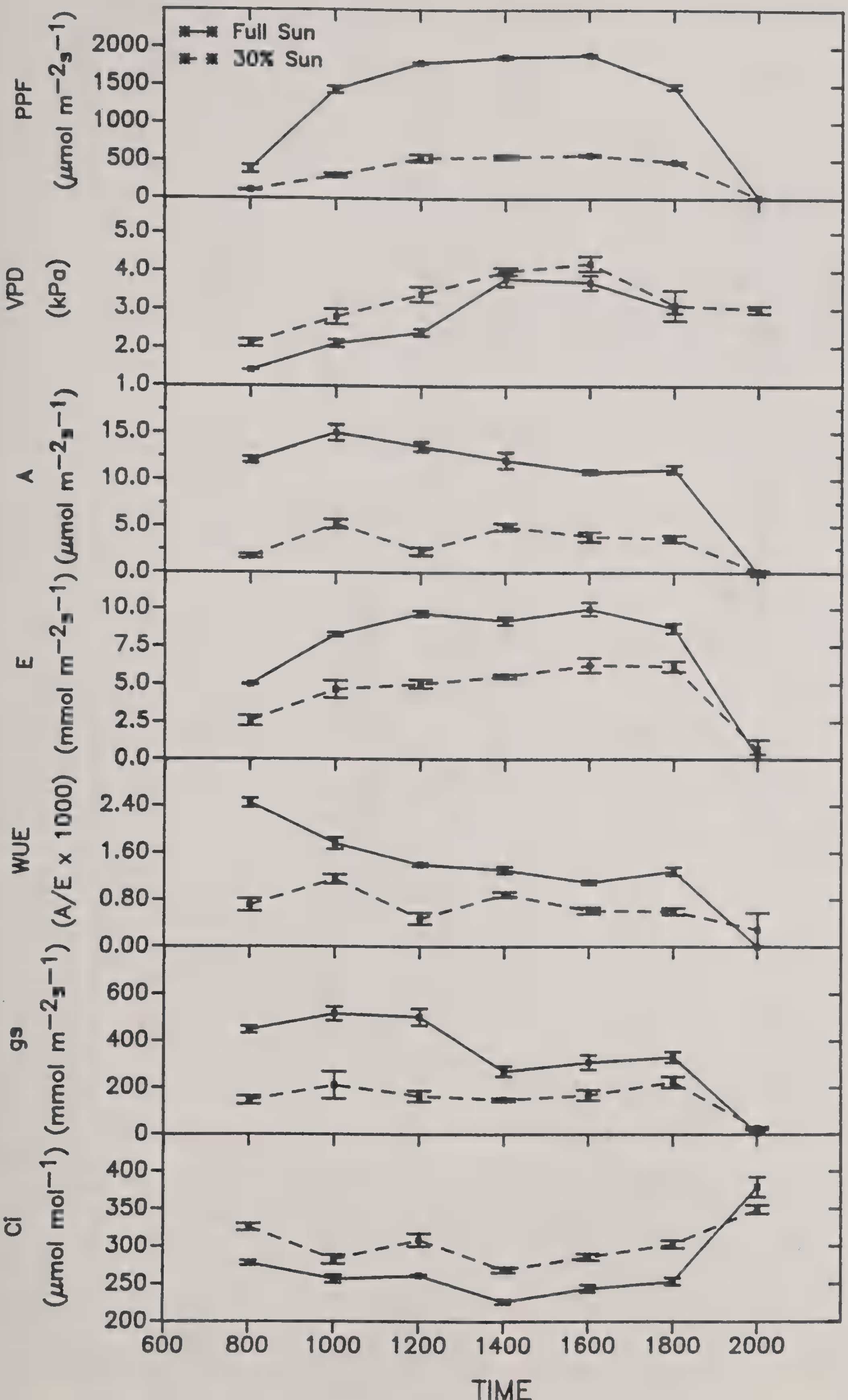

Figure 1. Diurnal characteristics of leaf gas exchange of 'Cape Fear' pecan leaves exposed to 100% or 30% sunlight for 14 days. Photosynthetic photon flux (PPF), vapor pressure deficit (VPD), net CO_2 assimilation (A) transpiration (E), water use efficiency (WUE), stomatal conductance (g_s) and intercellular CO_2 concentration (Ci) from 800 to 2000 HR. Circle and error bars represent mean ±1SE, n = 4. Leaf temperatures for sun and shade leaves, respectively were as follows: 800 HR, 21.1 ± 0.1 and 22.0 ± 0.3; 1000 HR 29.2 ± 0.4 and 28.3 ± 0.3; 1200 HR, 31.6 ± 0.2 and 31.4 ± 0.5; 1400 HR, 36.3 ± 0.4 and 34.0 ± 0.2; 1600 HR, 36.6 ± 0.3 and 35.2 ± 0.4, 1800 HR, 33.1 ± 0.1 and 31.4 ± 0.2; 2000 HR, 25.8 ± 0.1 and 26.0 ± 0.2 (mean ±1SE).

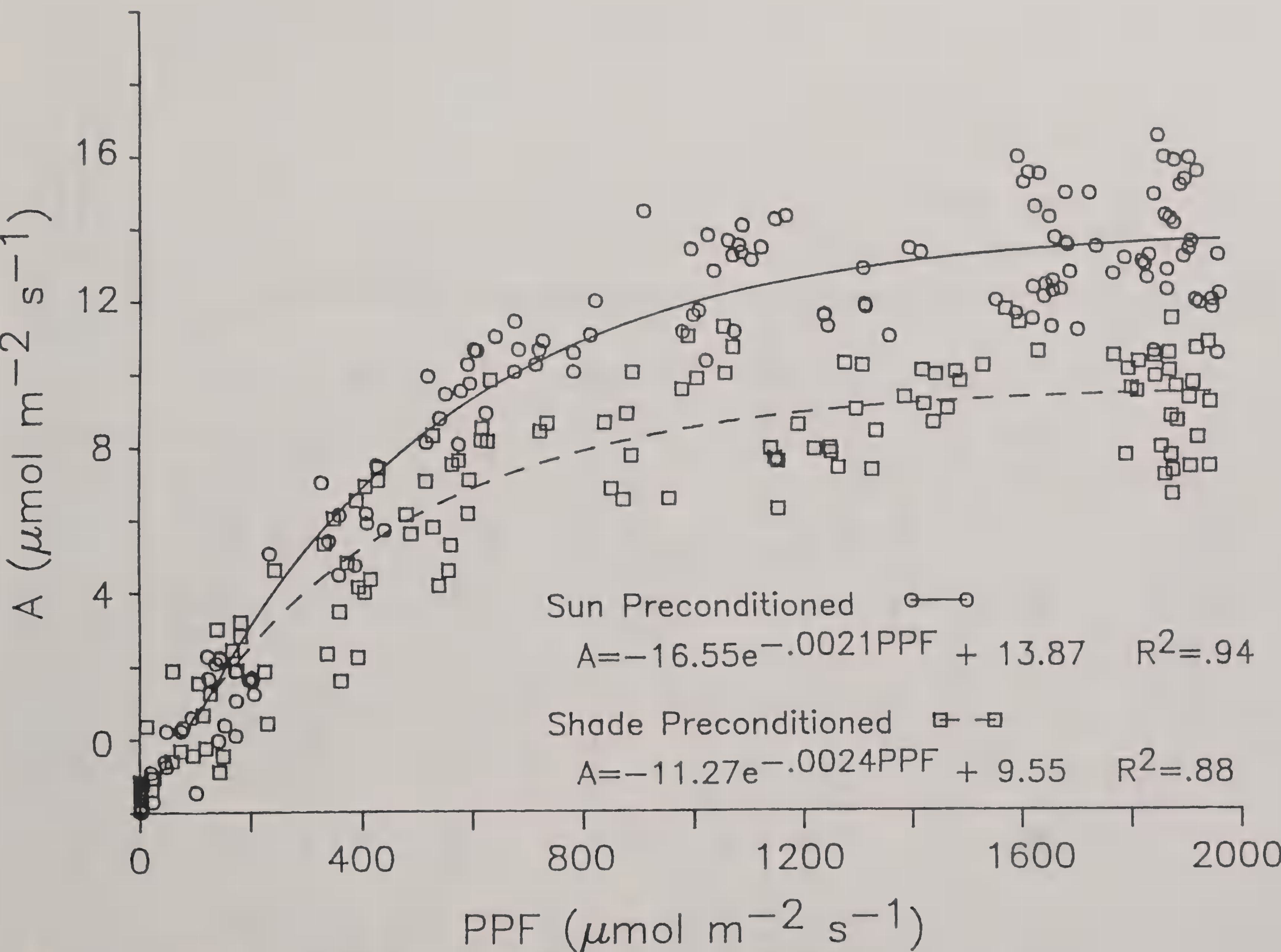

Figure 2. Net CO_2 assimilation (A) at different levels of photosynthetic photon flux (PPF) 'Cape Fear' pecan leaves preconditioned to 100 or 30% sunlight for 14 days. All trees were exposed to 100% sunlight for at least 1 hr prior to measurements. Data were collected from 4 100% sun- and 30% sun-preconditioned leaves. Vapor pressure deficits and leaf temperatures were 2.52 ± 0.04 and 2.46 ± 0.04 kPa, and 27.0 ± 0.2 and 26.7 ± 0.4C, respectively (Mean ±1SE).

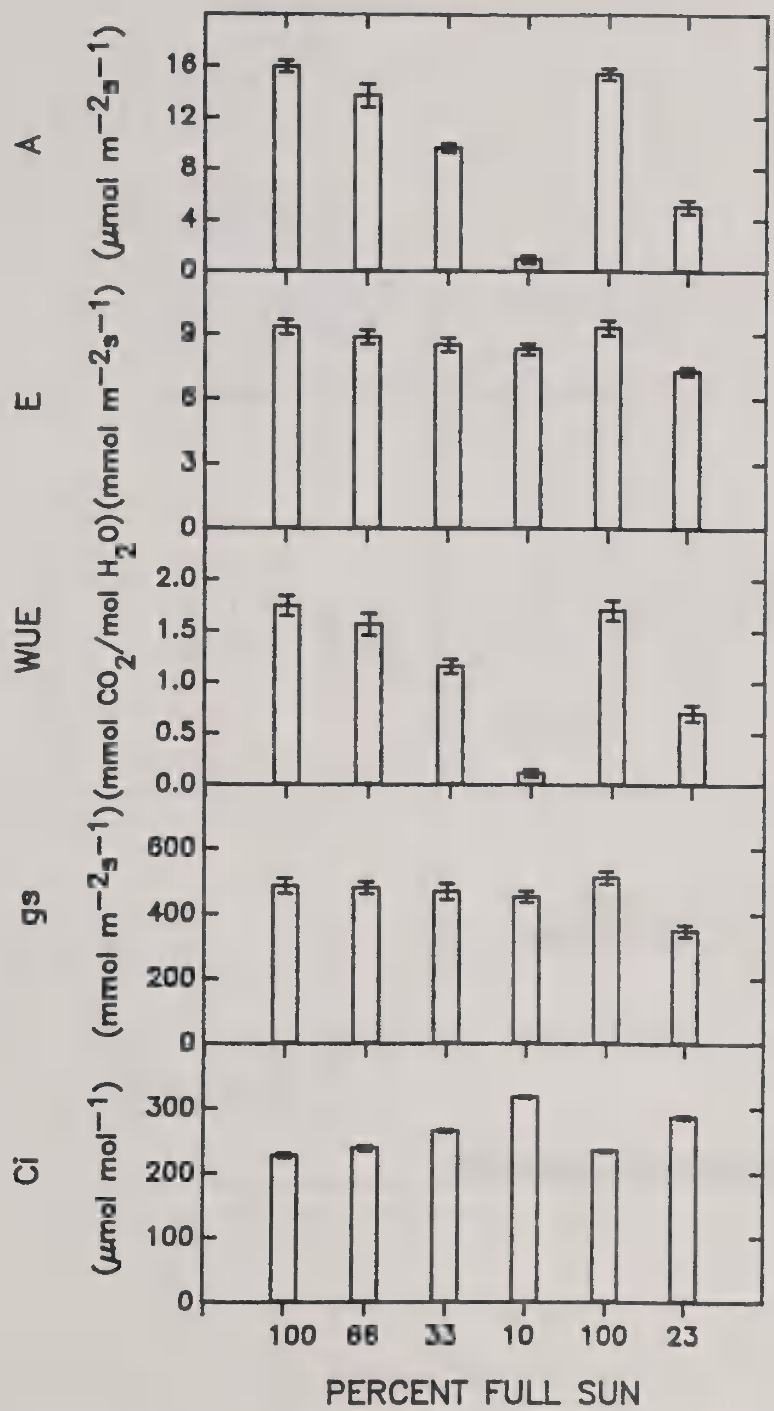

Figure 3. Net CO_2 assimilation (A), transpiration (E), water use efficiency (WUE), stomatal conductance (g_s) and intercellular CO_2 concentration (Ci) of 'Stuart' pecan leaves exposed to 100 (PPF = 2120 ± 14.5 µmol m^{-2} s^{-1}), 66, 33, 10 and 100% sunlight with each sequence lasting ≈ 80 sec. The last column (i.e., 23% full sunlight; 483 ± 21 µmol m^{-2} s^{-1}) represents the natural irradiance level of leaves measured in the canopy interior. Error bars correspond to mean ±1SE, n = 10. Leaf temperatures were 30.4 ± 0.8, 29.5 ± 0.8, 29.0 ± 0.9, 28.8 ± 0.7, 29.8 ± 0.8 and 29.1 ± 0.6C (mean ±1SE) for the 100, 66, 33, 10, 100 and 23% sunlight treatments, respectively. Vapor pressure deficits were 1.9 ± 0.1, 1.7 ± 0.1, 1.6 ± 0.1, 1.5 ± 0.1, 1.9 ± 0.1 and 1.8 ± 0.1 kPa for the 100, 66, 33, 10, 100 and 23% full sunlight treatments, respectively.

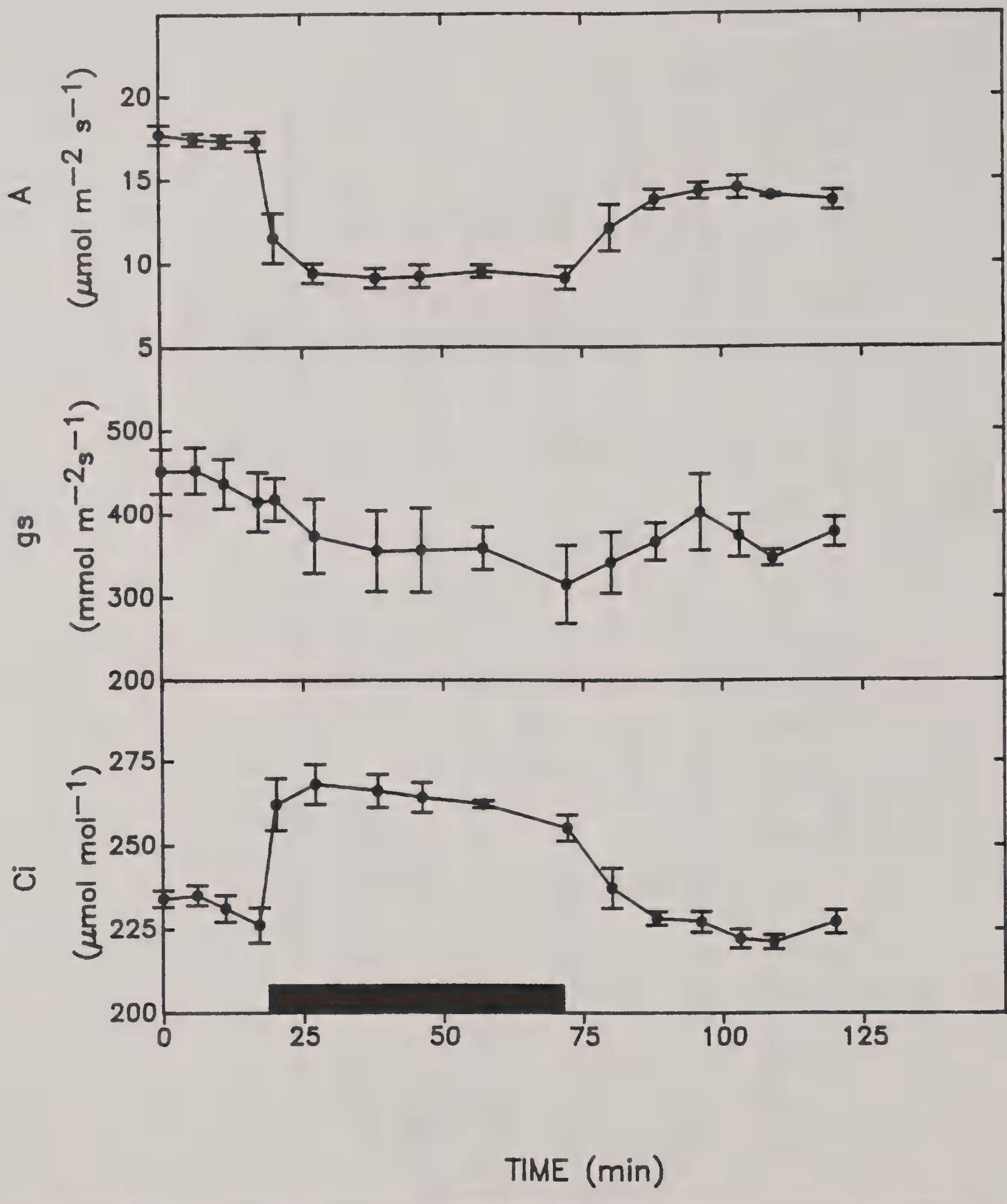

Figure 4. Effect of variable sunlight on net CO_2 assimilation (A), stomatal conductance (g_s) and intercellular CO_2 concentration (Ci) of 'Cape Fear' pecan leaves. Leaves were exposed to 20 min of 100% sun (PPF = 1924 $\pm$ 24 µmol m^{-2} s^{-1}), then 50 min of 33% sunlight (PPF = 583 $\pm$ 10 µmol m^{-2} s^{-1}) represented by the darkened horizonal bar, then 50 min of 100% sunlight. Circles and error bars represent means $\pm$1SE, n = 4. Leaf temperatures were 29.0 $\pm$ 0.2, 30.7 $\pm$ 0.3 and 35.1 $\pm$ 1°C (mean $\pm$1SE) for the 100, 30 and 100% sunlight periods, respectively. Vapor pressure deficits were 2.2 $\pm$ 0.1, 2.2 $\pm$ 0.1 and 3.3 $\pm$ 0.1 kPa for the 100, 30 and 100% sunlight periods, respectively.

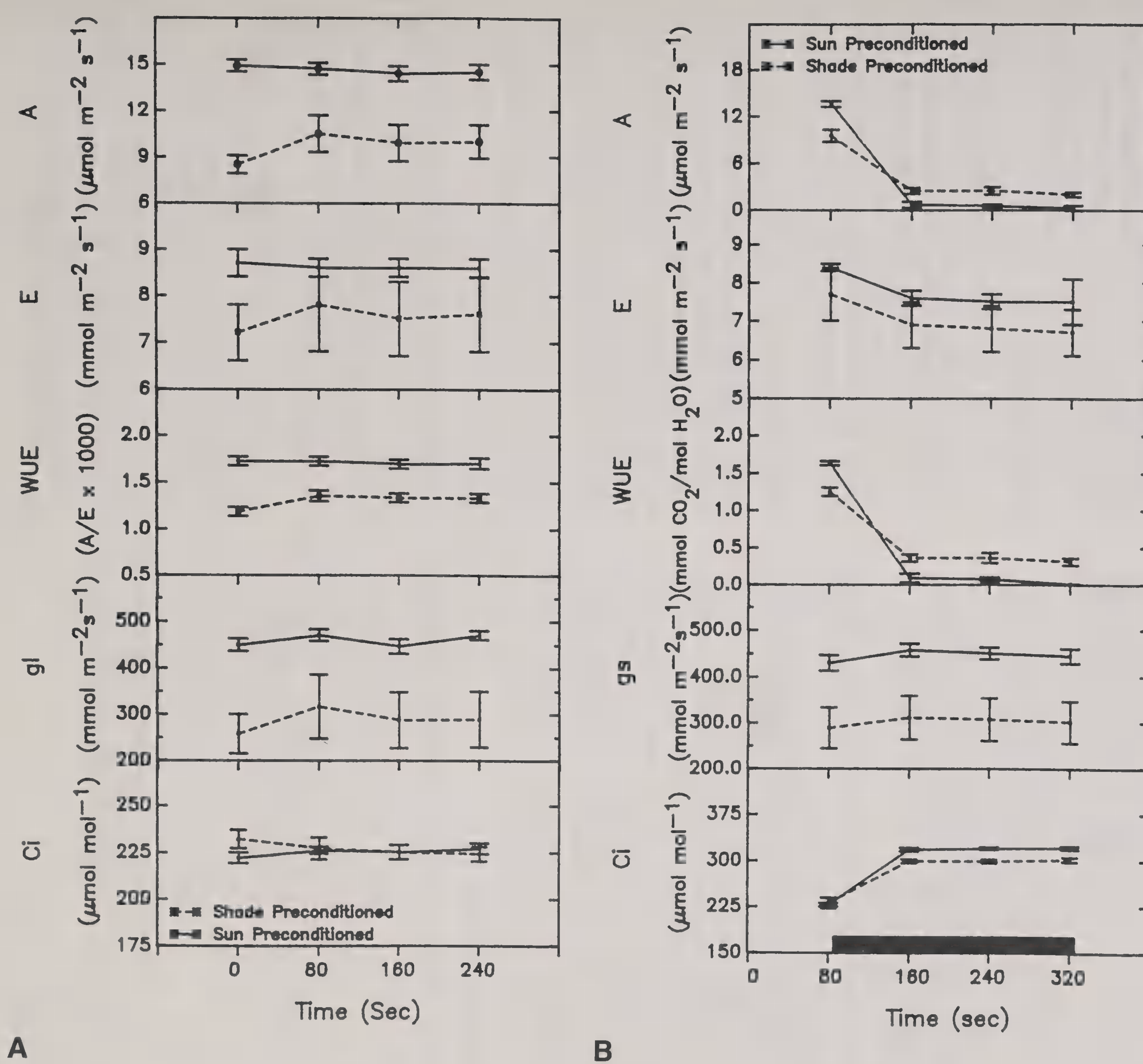

Figure 5. Net CO_2 assimilation (A), transpiration (E), water use efficiency (WUE), stomatal conductance (g_s) and intercellular CO_2 concentration (Ci) of 'Cape Fear' pecan leaves preconditioned to 100 and 10% full sunlight for 7 days (PPF in 100% sunlight = 1628 ± 27 μmol m^{-2} s^{-1}). Leaves were first exposed to 100% sunlight for 80 sec then to either 4 min of 100% sunlight (Fig. 5a) or 10% sunlight (Fig. 5b). The darkened horizonal bar represents the shaded period. Circles and error bars represent means ±1SE, n = 5. Leaf temperatures were 31.2 ± 0.2 and 28.9 ± 0.2°C for sun- and shade-exposed leaflets, respectively. Vapor pressure deficits were 3.0 ± 0.1 kPa and 2.3 ± 0.1 kPa (mean ±1SE) for sun- and shade-exposed leaflets, respectively.

MANAGING CROP LOADS IN PECAN

M.W. Smith[1], W. Reid[2] and D. Sparks[3]

ALTERNATE BEARING

Pecan fruit production is erratic and is typified by a year of high production followed by one or more years of low production. Lack of return bloom has been associated with early defoliation (Hinrichs 1962, Worley 1979) and with the inhibitory effect of developing fruit on return bloom (Crane et al. 1934, Malstrom and McMeans 1982, Smith et al. 1986, Reid et al. 1993). Crane et al. (1934) reported that 8 to 10 leaves per nut was the optimum leaf to fruit ratio for young 'Moore' trees (≈140 nuts/lb.) to induce annual crops. Removing 'Stuart' fruit during the early dough stage of kernel development improved return bloom (Sparks and Brack 1972). Fruit removal increases the leaf to fruit ratio and removes the inhibitory effect of developing fruit on pistillate flower induction.

Pecan flower and fruit development (Sparks 1986), and the alternate bearing problem (Sparks 1974, Wood 1991) have been reviewed. Alternate bearing is apparently caused by a lack of stored carbohydrates during the fall, coupled with certain phytohormonal or growth-regulator balances to control flower induction and development (Sparks 1974, 1986; Smith et al. 1986, Wood 1991). Sparks (1974, 1986) and Wood (1991) pointed out that although both endogenous growth regulators and carbohydrate reserves regulate flowering, carbohydrates are often the most limiting factor controlling flower initiation and development. This hypothesis supports orchard management which promotes healthy leaves with a high leaf to fruit ratio to reduce alternate bearing.

FRUITING STRESS

Excess fruit loads cause several problems in addition to alternate bearing. Heavy fruit loads frequently result in a large percentage of poorly developed kernels that are either not marketable or have little value (Hunter 1968, Reid 1986). This problem is more severe in cultivars with large fruit size or that have several fruit per cluster. Also the problem of over-production resulting in poor fruit quality becomes more severe as the trees mature, probably because leaf to fruit ratios decline.

Susceptibility to cold damage is substantially increased when trees are over-loaded with fruit (Smith and Cotten 1985, Wood 1986, Smith et al. 1993a). Cultivars vary in susceptibility to cold injury (Cochran 1930, Hinrichs 1965, Madden 1978, Payne and Sparks 1978, Smith and Couch 1984, Wood 1986, Smith et al. 1993a), but susceptibility can be highly confounded by crop load. In fact, relative crop loads should be reported when cold hardiness of cultivars is reported after a test winter.

Shuck (involucre) disorders have also been associated with crop over-loads. Stick-tights (shucks which would not open at fruit maturity) were decreased in over-loaded 'Mohawk' trees by partial crop removal (Smith and Gallott 1990). Shuck decline (also called shuck dieback, shuck disease, and tulip disease) was decreased in 'Wichita' trees by partial crop removal (Sparks et al. 1994).

Tree breakage is increased by over-production. Breakage becomes common on over-loaded trees when fruit reach the dough stage, and is more severe on certain cultivars, on trees that are poorly trained, cultivars with an upright tree structure, and in climates subject to violent thunder storms. At times loss from tree breakage can be substantial, both from clean-up costs and tree losses.

FRUIT THINNING

Substantial evidence exists that fruit thinning can be used with good cultural practices to reduce the deleterious effects of over-production. Fruit thinning is commercially successful on other crops, such as apple and peach, to manage crop loads for high fruit quality and uniform annual cropping. Work on pecan suggested that fruit removal would enhance return bloom (Sparks and Brack 1972), that there was an optimum leaf to fruit ratio to achieve relatively uniform annual cropping (Sitton 1931, Crane et al. 1934), and that over-production caused poor-quality, low-value nuts (Hunter 1968, Reid 1986).

Several scientists have evaluated various chemical fruit thinning agents on pecan (Dodge 1944, Sharpe 1955, Smith and Harris 1957, Amling and Dozier 1965, Hinrichs et al. 1971, Wood 1983, 1985). Although some of these thinning agents have shown promise, none have been registered for use on pecan, and the likelihood that one will is minimal.

The first mechanical fruit thinning trials were conducted in 1984 on over-loaded 'Mohawk' trees in central Oklahoma. We used a tractor-mounted trunk shaker fitted with hard neoprene pads, typical of trunk shakers used in Oklahoma. The bark on ≈10% of the trees we shook during August was damaged. Therefore, we converted the pads to a donut style, typical of those used for cherries. Grease was applied under the flaps covering the donut pads to allow any slippage at this site rather than damaging the bark. This arrangement eliminated all trunk damage.

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Preliminary mechanical fruit thinning trials in 1986 and 1988 indicated that partial crop removal while fruit were in the liquid endosperm stage (water stage) improved kernel percentage of 'Mohawk' and 'Shoshoni' and increased nut weight and kernel grade of 'Mohawk' (Smith and Gallott 1990). Return bloom of 'Shoshoni' was substantially increased; however, neither thinned nor unthinned 'Mohawk' trees flowered the following year. These results suggested that mechanical fruit thinning was a viable approach to combating the problems of poor fruit quality during years with over-production and alternate bearing. However, we needed to determine the optimum time to thin fruit and the optimum crop load to achieve high-quality fruit with adequate return bloom.

First we determined the optimum time to thin by hand removing fruit at selected times, then measuring return bloom. Fruit were removed on 'Mohawk', 'Giles', and 'Gormely' trees at five times during the growing season as determined by fruit phenological age: immediately after post-pollination drop, at 50% ovule expansion, at 100% ovule expansion or water stage, during the onset of the dough stage, and 2 weeks after the dough stage (Reid et al. 1993). Return bloom of all cultivars was increased by fruit removal during ovule expansion. Removing 'Mohawk' and 'Giles' fruit shortly after pollination induced the greatest return bloom. Return bloom in the small-fruited 'Gormely' was equally stimulated by fruit removal at any time from post-pollination through ovule expansion, a result indicating that early fruit removal may be more important for large- than for small-fruited cultivars. Our studies indicated that the fruit should be thinned as soon as feasible, with the benefits of thinning diminishing rapidly when nuts reach the dough stage. Experience has indicated that fruit cannot be dislodged from the tree with a trunk shaker until the ovule is about 50% expanded.

Next we used two cultivars, 'Mohawk' a large- fruited cultivar and 'Giles' a medium-fruited cultivar, to determine optimum crop load (Smith et al. 1993b). Trees bearing an excessive crop load were thinned during ovule expansion with a trunk shaker to give a wide range in the percentage of shoots that retained fruit clusters. Fruit thinning improved the kernel percentage (Fig. 1), nut weight, and kernel grade (Fig. 1) of 'Mohawk', but nut characteristics of 'Giles' were not affected by fruit thinning. Cold injury of 'Mohawk', caused by a sudden temperature drop in the fall, was decreased by fruit thinning (Fig. 2). Fruit set of both 'Mohawk' and 'Giles' (Fig. 3) the following year was improved by fruit thinning. Relatively uniform yields of 'Giles' were obtained in 1991 and 1992 when trees were thinned to 60% to 70% of the shoots retaining fruit in 1991 (Table 1). We recommend that 'Mohawk' trees be thinned so that 50% to 60% of shoots at mid-canopy height retain fruit after thinning, and 'Giles' be thinned to 65 to 70% of the shoots retaining fruit. Although our recommendations are based on the percentage of shoots retaining fruit, we want to point out that cluster size is reduced in the clusters that remain (Smith et al. 1993b, Sparks et al. 1994). Thus, if thinning reduces the fruit load from 90% of the shoots with fruit clusters to 50% of the shoots with clusters, about 60% to 70% of the fruit may be removed.

Several production problems associated with over-production were addressed in a fruit thinning study conducted in south Texas by Sparks et al. (1994). Pecans grown in climates with warm temperatures during fruit maturation frequently germinate before shucks open (vivipary), rendering them unmarketable. This study was conducted in an area of Texas that frequently experiences problems with vivipary. Also, certain cultivars are extremely susceptible to shuck decline, resulting in unmarketable nuts. 'Wichita', one of the most susceptible cultivars to shuck decline, was thinned with a mechanical shaker to reduce the crop by 0% to 77%. Fruit thinning decreased shuck decline and premature germination, and increased the percentage of edible kernels (see Pecan Shuck Disorder — A Horticultural View in this proceedings). The maximum marketable kernel yield corresponded to 72% of the shoots retaining fruit. Subsequent observations indicated that return bloom was adequate when about 25% of the shoots retained fruit.

We have frequently observed that nut quality of some medium- to large-fruited cultivars can be substantially improved by thinning with little effect on return bloom. Adequate return bloom of these cultivars can be achieved, but the trees must be thinned more severely. In some cases, sufficient thinning to achieve adequate return bloom is not feasible because little crop would remain. On other medium- to large-fruited cultivars improved nut quality with adequate return bloom can be achieved with moderate thinning levels. The most consistent response observed with small-fruited cultivars has been improved return bloom. There is usually little effect on nut quality of small-fruited cultivars, unless they have large fruit clusters.

Pecan growers in several states are using mechanical thinning on a trial basis. If mechanical thinning proves to be commercially feasible, both scientists and growers will refine techniques and recommendations. For instance, by shaking a large tree at right angles thinning uniformity can be improved. It is likely that thinning goals will need to be developed for each of the major cultivars. Also, thinning goals may be developed to ensure good nut quality, and a second goal that would ensure good quality and return bloom. Limited observations suggest that the tree structure of some cultivars are more adaptive to mechanical thinning than others. Estimating crop loads while thinning is difficult, and improved methods may be needed. Also, if mechanical thinning is adapted by the industry, several of the prolific cultivars that were discarded may need to be reevaluated.

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Table 1. Yield of 'Giles' the year fruit were thinned (1991) and the following year (1992).

		Yield (kg/tree)		
Thinning	Fruiting shoots retained (%)	1991	1992	Total
None	90 - 98	31	3	34
Light	70 - 80	28	5	33
Medium	80 - 90	21	10	31
Heavy	60 - 70	18	16	34

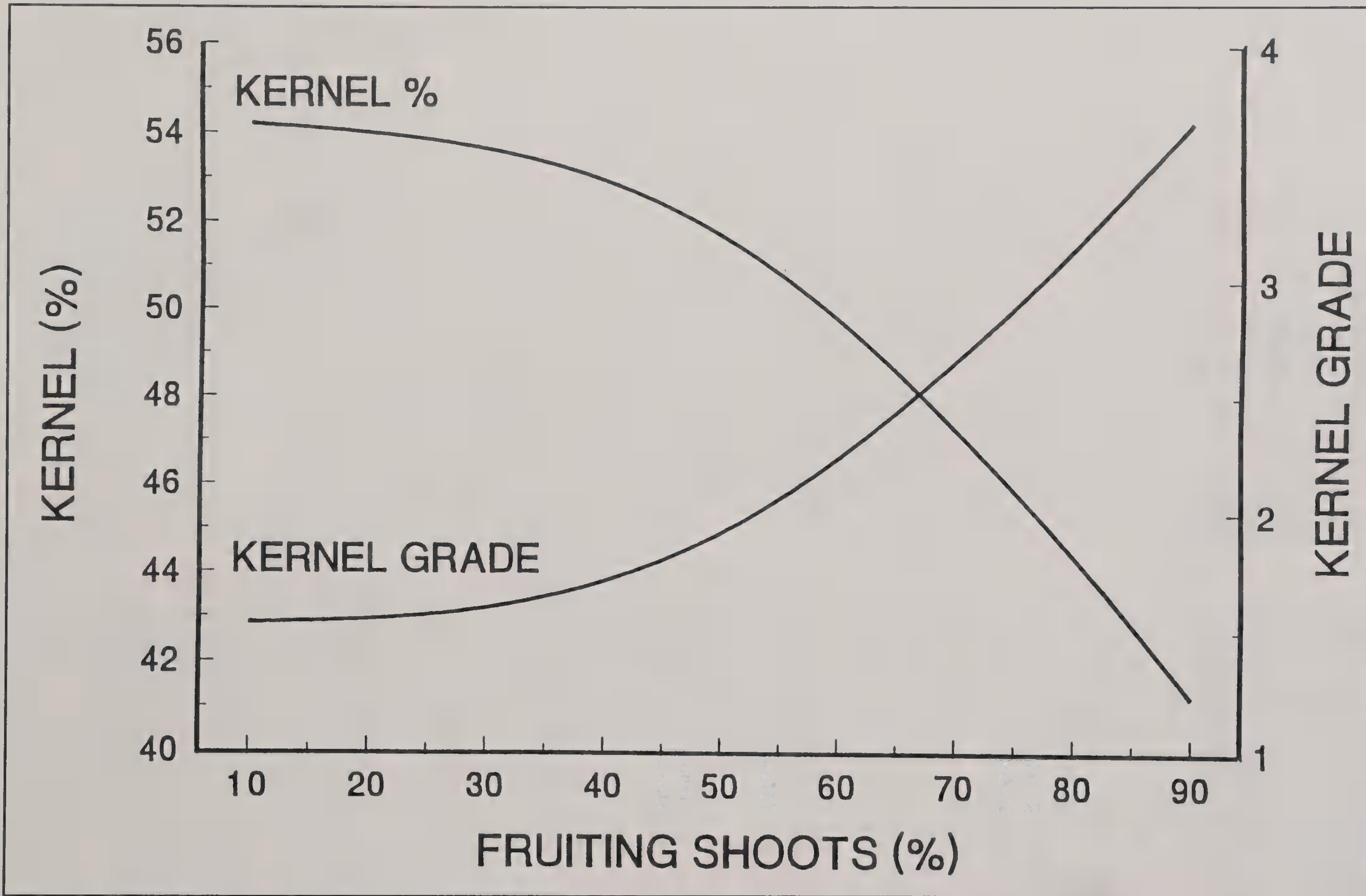

Figure 1. The relationship between the percentage of fruiting shoots per tree after fruit thinning 'Mohawk' pecan and the kernel percentage ($y = 54.4 - 2 \times 10^{-5}x^3$, $r^2 = 0.64^{***}$) or kernel grade ($y = 1.6 + 2.8 \times 10^{-6}x^3$, $r^2 = 0.73^{***}$). Kernel grade: 1 = brightly colored, full bodied and solid, 2 = brightly colored and light weight, 3 = amber, and 4 = poorly developed and shriveled. The kernel rating system did not consider insect damage.

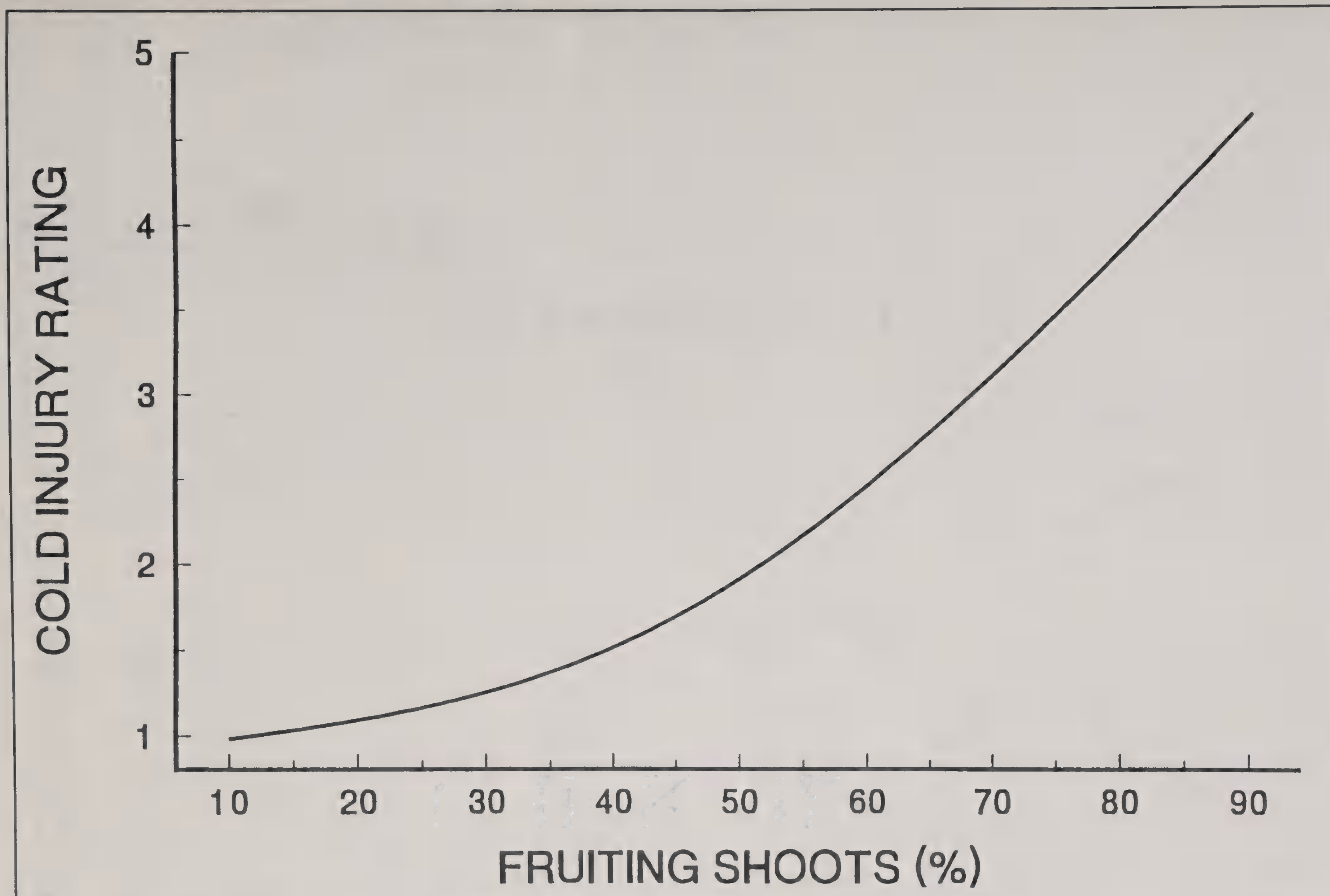

Figure 2. The relationship between the percentage of fruiting shoots per tree after thinning 'Mohawk' pecan on 31July 1991 and the tree cold injury that occurred on 2 and 3 Nov. 1991 ($y = 1.1 + 5.1 \times 10^{-6}x^3$, $r^2 = 0.72^{***}$). Cold injury was rated during June 1992 using the following scale: 1 = no injury, 2 = death of many 1- and 2-year-old shoots, 3 = death of $\geq$ 3-year-old branches, but no scaffold death, 4 = death of at least one scaffold limb, and 5 = tree death.

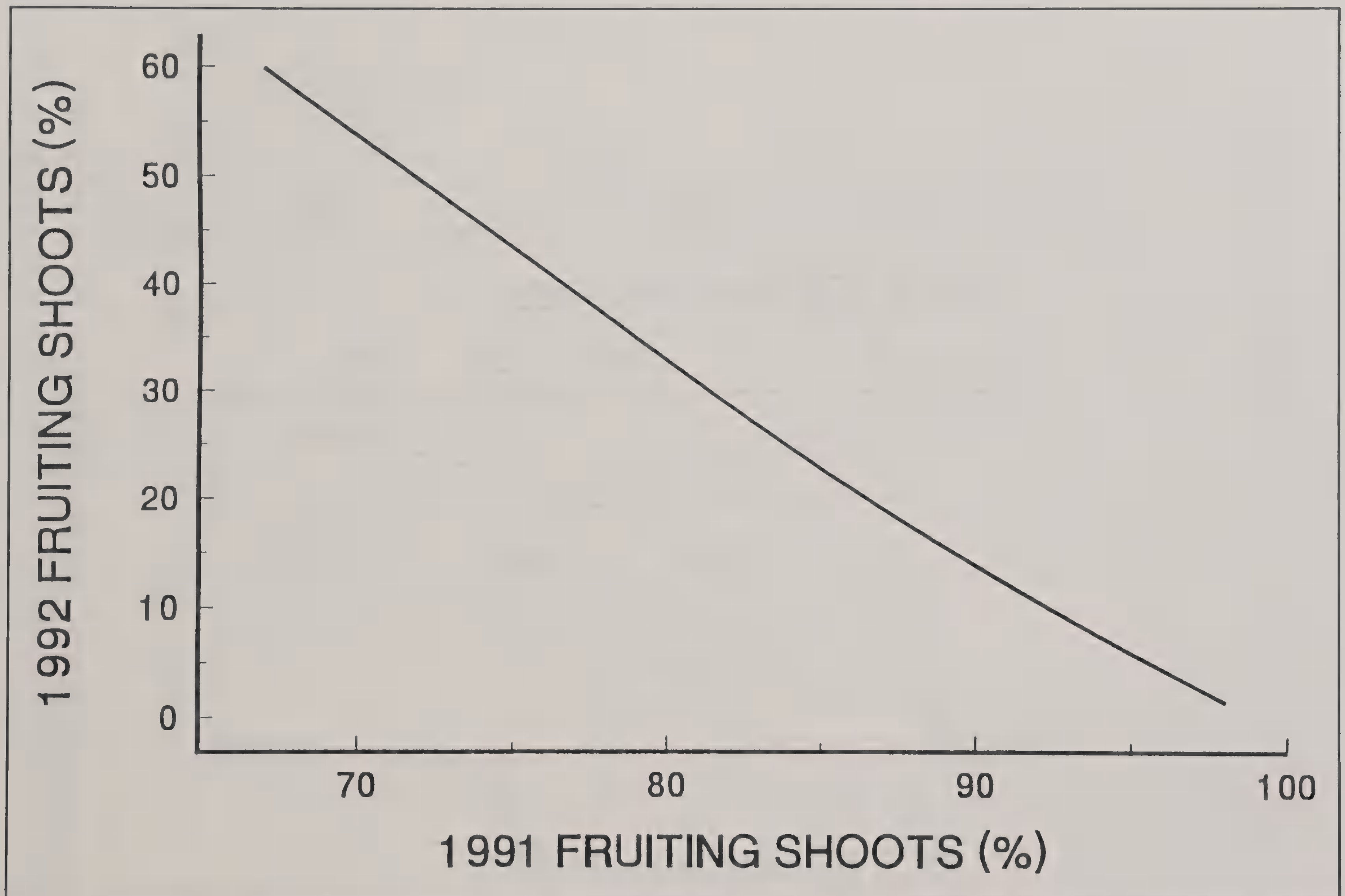

Figure 3. The relationship between the percentage of fruiting shoots per tree after thinning 'Giles' pecan in 1991 and the percentage of fruiting shoots in 1992 ($y = -46.1 + 469576/x^2$, $r^2 = 0.51$***).

ROOTSTOCK DEVELOPMENT

L.J. Grauke[1] and T.E. Thompson[2]

ABSTRACT

Pecan [*Carya illinoinensis* (Wangenh.) K. Koch] rootstock selection is empirically performed in commercial nurseries and varies by geographic region. Seedlings vary in inception and duration of growth as a function of seed origin. Seedlings grown from open pollinated seedstocks commonly used in the nursery industry can be distinguished on the basis of phenology. Variation in phenology results in different levels of exposure to damaging spring and fall freezes. Cold hardiness of seedlings may be influenced by factors other than phenology. Minimum temperature, as well as the length of the growing season, should be evaluated for an orchard site when selecting an appropriate rootstock. Seedling size is enhanced by selecting seedstock south of the nursery site. Risk of freeze damage increases as seedlings are moved north of seedstock origin. Pecan growers should be cautioned against purchasing trees propagated on rootstocks used south of their geographic region.

In the Southeastern U.S., water hickory [*Carya aquatica* (F. Michx.) Nutt.] occurs on poorly drained, wet sites. Both water hickory and the pecan-water hickory hybrid (*Carya* X*lecontei* Little) are used as rootstocks for pecan in the Southeast. Performance of those rootstocks is dramatically influenced by site, and is inferior to pecan rootstocks on well drained sites. Growers should be knowledgeable of the rootstock used to produce their trees, and should use only those suited to their site.

In pecan research orchards, the variability introduced by rootstock should be recognized and either controlled as a test variable or minimized by the use of a single open-pollinated seedstock. Efforts to improve rootstock performance must be targeted at specific geographic areas sharing uniform climatic and edaphic conditions. Inclusion of native entries in local pecan nurseries is advised. Improved methods of evaluating seedling families are needed to improve prediction of rootstock performance in targeted environments.

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INTRODUCTION

Rootstock selection is a critical decision that can effect the survival (Heiges 1896), as well as the performance of trees (Grauke and Pratt 1992). Despite occasional dramatic manifestations, most rootstock effects are subtle and may go unnoticed, unless orchards are designed specifically to test for rootstock effects. Even in well-designed test orchards, inherent tree variability complicates interpretation, making researchers hesitant to invest the time and effort necessary for field testing. Instead, researchers have concentrated on methods to reduce the inherent variability of open pollinated seedling rootstocks, either by controlled pollinations (which is not practical for the commercial industry), or by clonal propagation (which has not been successful). Rootstock selection has been left to nurserymen, who have operated within geographic and climatic constraints. The objective of this paper is 1) to report on the current status of the commercial industry concerning rootstock usage 2) to review the evidence concerning the need for regional rootstock development, and 3) to make recommendations for the areas where research could contribute to the continued "evolution" of improved rootstocks for pecan.

ROOTSTOCK USAGE IN THE PECAN NURSERY INDUSTRY

A few definitions may be helpful. The "seedstock" is the source of the seed planted to produce rootstocks. A seedstock may be a single, unduplicated, native tree (e.g., 'Little Jewel'). Seed might also be collected from many trees of the same cultivar (e.g. 'Elliott') and still be a single seedstock. Seedlings arising from the same seedstock are considered a "family". Seedlings of a family may be full siblings (having the same pollen and pistillate parent) or half siblings (having different pollen parents). Full sib seedlings may be the result of either cross- or self-pollination. Seed produced without the intervention of man is termed open-pollinated seed, the parentage of which will depend on the composition, spacing and dichogamy of associated trees. It is obvious from the above that there will be variability within seedstocks. Sources of that variability include the pollen parent, and any environmental or cultural conditions that influence nut quality, as reviewed elsewhere (Grauke, 1991). "Provenance" is the geographic area of genetic origin.

The commercial pecan nursery industry relies on open-pollinated seed for the production of rootstocks. Current choice of seedstocks among commercial pecan nurserymen was surveyed by telephone. Nurseries were called if they appeared in the recently updated directory used for correspondence with pecan nurseries concerning the 1994 release of 'Navaho'. During the course of the survey, a few nurseries were added to the directory, and several were deleted, having gone out of business. Questions were asked concerning seedstocks used, and the criteria of selecting those stocks.

Several factors influence the choice of seedstock, including seed availability, nut fill, nut size, nut shape, seedling vigor, stand uniformity, and root characteristics. Most nurserymen note that local availability is important in their choice of seedstock. Those who harvest from their own trees usually credit the seedstock with other valuable characteristics, such as improved germination or vigor. Those who purchase seed usually target a preferred seedstock for particular reasons, but plant available seed in its absence. Well filled nuts are recognized as being important for good germination. Small nuts are often preferred, especially when seed is purchased, since more nuts per pound increases potential production. Round nuts are generally preferred over long nuts, if preference due to shape is mentioned, due to improved performance in some mechanical planters. Some nurserymen note increased predation with particular seedstocks, notably 'Mahan' and 'Stuart'.

SOUTHEAST

Preferred seedstocks vary by geographic region (Fig. 1). In the Southeast, 'Elliott', 'Curtis', 'Stuart' and 'Moore' are the most commonly used seedstocks, although many others (including water hickory) are used either occasionally or in small amounts. 'Elliott' is the most common seedstock mentioned by southeastern pecan nurserymen. The excellent germination of seed and vigor of seedlings are the most common justifications for its use. Those observations are corroborated by research (Grauke and Pratt, 1985). 'Curtis' is commonly mentioned with 'Elliott' as a preferred seedstock, but was cited as preferred over 'Elliott' by only one nurserymen from Florida. White (1982) compared the response of 'Curtis' and 'Stuart' seedlings to additions of lime in topsoil and subsoil. He noted that performance of both seedstocks was limited by acidic subsoil conditions, but suggested that 'Curtis' may be more tolerant of acid subsoil conditions than 'Stuart'.

'Moore' was mentioned as the preferred seedstock by nurserymen in northeast Texas and central Louisiana, although availability of good seed was mentioned as an occasional problem. Sitton and Dodge (1938), in tests conducted in Shreveport, Louisiana, reported yield and tree size increases with 'Moore' as a rootstock as compared to 'Waukeenah'. In Florida and Georgia, some nurserymen continue to use 'Waukeenah, a sib of 'Moore'.

'Stuart' is readily available and is used by several nurserymen in the Southeast, and was mentioned as a seedstock north to Missouri and west to California. The delayed growth of 'Stuart' progeny is considered a liability to some growers in the south, since it delays spring budding. That same characteristic may contribute to the occasional use of 'Stuart' as a rootstock in the north, although its hardiness should be verified before it is relied upon.

In the disease-prone southeast, some nurserymen make seedstock selections based on increased disease resistance of seedstock progeny. 'Pioneer' (AL) is used in one Alabama nursery, based on the observation that it produces scab resistant progeny.

Water hickory seed is used to a limited extent in Southeastern nurseries. The species occurs on low, wet sites from Texas east to Florida (Thompson and Grauke 1991), in an area that largely overlaps the southeastern pecan industry. Nurseries that select it as a seedstock specifically target its use on wet, poorly drained sites. Toliver and Stauder (1982) reported increased growth on water hickory and hybrid (*Carya* X*lecontei* Little) seedlings, as compared to pecan, when the three seed sources were compared on a poorly drained site in south Louisiana. Grauke and O'Barr (1992) reported increased growth of pecan and hybrid over water hickory, when the seedstocks were compared on a well drained site in north Louisiana. Sitton and Dodge (1938) also found reduced growth of pecan scions on water hickory stocks in north Louisiana. In addition, they reported increased iron chlorosis with the water hickory stocks, an observation corroborated by Grauke and O'Barr (1992) who found the hybrid intermediate to the two parents in all respects evaluated. There is also occasional unintentioned use of water hickory or hybrid seedstock. Seedstock collected by the Louisiana Forestry Commission for use in the Columbia Nursery was evaluated in 1984 and found to include water hickory and hybrid seed. Some pecan nurseries, as well as individual pecan growers, obtain one year old seedlings from the Columbia nursery for propagation and orchard establishment. It is important that water hickory or hybrid rootstocks be used on a "prescription basis" only. If site limitations include excess moisture on poorly drained soils, hybrid rootstocks may be helpful. However, inherent limitations to productivity and difficulty in managing such sites should be recognized.

SOUTHWEST

In the South Central and Southwestern Pecan Belt, 'Riverside', 'Burkett', 'Apache', and 'VC-168' predominate as seedstocks, although many others (including selected natives) are also used. The use of 'Burkett' and 'Riverside' is primarily due to the availability of good quality seed, according to the nurserymen surveyed. As good 'Burkett' seed becomes harder to find, other seedstocks are being used, including the 'Burkett' progeny 'Apache'. 'Riverside' is used as a seedstock as far east as the Tyler, Texas, area where one nursery uses both 'Moore', an eastern stock, and 'Riverside', a western stock.

Of the nurseries surveyed in the southwest, two reported the use of native or seedling selections as seedstocks. 'Little Jewel' (syn. 'Little Gem'), selected by Horace Brown from the Nueces River in Uvalde Co., Texas, is used in a small nursery operation on the basis of a reputation for tolerance

to alkaline soils. That seedstock has been included in test plantings to verify its reputation.

The other seedling selection is 'VC-168', used in California. The history of pecan rootstock use in California is both interesting and undocumented. According to Eugene Cripe of Linwood Nursery, Turlock, CA, several seedstocks were used in California during the 1960s, including 'Indiana'. Although it was known locally as 'Linwood', 'Indiana' is a 1909 selection from Indiana, thought by some to be a seedling of 'Busseron' (Littlepage 1911). Seedlings grown from 'Indiana' seedstock in California were slow growing, and required three years to reach grafting size. This is consistent with observations of the performance of seedstocks in relation to provenance (Grauke 1991). In an effort to produce more vigorous seedlings, other seedstocks were evaluated until an Arizona seedling selection was found that produced vigorous progeny. That selection was given the name 'VC-168', and has been the preferred seedstock at Linwood Nursery since the early 1970s, although many others have been used occasionally. The vigor and high seedling quality of 'VC-168' has been corroborated in our tests (data not reported). Grafted trees in repository collections in both Brown and Burleson County, Texas, have been killed or severely damaged by freezes. Hardiness of seedlings should be verified.

Among the other seedstocks used in California are 'Shoshoni', 'Choctaw', 'Wichita', and 'F.W. Anderson'. In the patent for 'F.W. Anderson', the inventor claimed the tree to be free of Zn problems on alkaline soils (Anderson 1964). The seedling originated from 'Govett' (called 'Caloro' in the patent, but see Brooks, 1964). 'Govett' is a native selection from Guadalupe Co., TX, an area characterized by alkaline alfisol soils, the predominate soil group found in the pecan growing region of California.

NORTH

The northern pecan nursery industry has different constraints, and a different structure, than the southern industry. The north accounts for only a small percentage of the total U.S. pecan production, and most of that comes from cold-hardy native trees. Many growers of improved northern pecan cultivars have only a few trees of each of several cultivars, produced by grafting their own native trees. The exchange of scionwood is often a more important nursery function than the production of grafted trees. There are relatively few northern nurseries producing grafted trees. Native seedstocks are widely used, along with cold-hardy seedstocks such as 'Giles', 'Peruque', 'Major', and 'Colby'. Some relatively large northern pecan nurseries rely on bulk collections of local natives as seed.

Throughout the pecan belt, many small nurseries have gone out of business, or are in the process of reducing (and discontinuing) operations. Consolidation of the nursery industry in a few large "regional" nurseries may greatly reduce the number of seedstocks currently being planted. Furthermore, as local nurseries become less available, the temptation to purchase trees from distant sources is increased. Several nurserymen mentioned interregional cooperation with other nurseries in supplying trees, or targeted sales outside their geographic region. Pecan growers purchase trees primarily on the basis of cultivar, without regard to rootstock. This practice carries considerable risk, especially as trees are moved from south to north. The risk has been recognized since the early days of pecan orchard establishment. Heiges (1896) reported the success of a Massachusetts grower in growing nuts from Illinois, while seedlings grown from Texas nuts were winterkilled. Littlepage (1911) noted that only northern rootstocks should be used in the north, and cited his personal experience with freeze mortality of trees with southern rootstocks. Contemporary growers continue to relearn that lesson. A pecan grower planted 80 acres of pecan trees in Kentucky, near the confluence of the Ohio and Mississippi Rivers. The trees were on southern rootstocks ('Riverside', 'Curtis' and 'Elliott'). Of the 1000 grafted trees planted in 1984, he estimated that 90-95% were lost to freeze. He replanted with 3500 similar trees in 85-86, of which 90-95% were lost to freeze. He now uses local natives as rootstocks, and has had no further trouble.

Patterns of rootstock usage in some areas are driven by unrelated factors. In 1988, pecan nut casebearer (*Acrobasis nuxvorella* Neunzig) was found on pecan trees in New Mexico and far West Texas (Glogoza et al. 1989). As a result, a quarantine was placed on pecan nursery stock going into Arizona and California. There are no pecan nurseries in Arizona. Prior to the quarantine, Arizona pecan growers bought most of their trees from New Mexico, where 'Riverside' and 'Burkett' are the predominate rootstocks. Since the quarantine, much stock has been purchased from California, where 'VC-168' (apparantly less cold-hardy) is the predominate rootstock.

REGIONAL ROOTSTOCK DEVELOPMENT

A review of the geographic and climatic constraints to tree growth experienced across the pecan belt may contribute to the formation of realistic boundaries for rootstock development and selection of improved seedstocks.

TEMPERATURE RANGES

Freezing temperatures in the spring and fall delimit the growth of pecan in each region. The duration of the growing season ranges from about 300 days in parts of the Gulf Coast and southwestern Arizona, to less than 180 days in northern Missouri and Illinois, and southern Iowa and Indiana (Fig. 2). The southeastern corner of Arizona has a mean freeze-free period of less than 210 days (comparable to southern Kansas) (Fig. 2), yet receives minimum

temperatures of only 10 to 15 F (comparable to central Texas) (Fig. 3).

Families of open pollinated pecan seedlings can be distinguished in the field on the basis of timing of growth, both in the spring and fall. In the spring, inception of growth of seedlings grown from 'Curtis' and 'Elliott' seed was significantly earlier than growth of seedlings from 'Moore', 'Riverside', and 'Burkett' (Grauke and Pratt 1992). When seedlings of different seedstock families were grafted with 'Candy' scions, inception of growth was influenced by seedstock. Patterns of growth for other scions (e.g., 'Cape Fear' and 'Stuart') did not show the influence of rootstock. Bud growth was evaluated at a stage when scion growth was just beginning for those cultivars, reducing resolution of differences due to rootstock. Seedlings of 'Burkett' received significantly less damage from a late spring freeze (-5C, 22 May) than did seedlings of either 'Curtis', 'Elliott', or 'Riverside', but could not be distinguished from seedlings of 'Moore'. In general, seedlings recieved moderate to severe damage if they had advanced to the stage of leaf burst. Differences in the performance of field grown seedlings might be related to origin of the seedstocks: 'Elliott' and 'Curtis' were selected in Florida, an area with long growing seasons and mild winters. 'Burkett' and 'Riverside' were native selections from an area of Texas with shorter growing seasons and colder winters. Characterization of differences in amount of chilling required to intitiate growth in different seedstocks should be evaluated under more controlled conditions, using methods such as those of Smith et al. (1992). Those authors found a chilling requirement of about 900 h at 6C to achieve >50% budbreak of seedlings grown from open-pollinated 'Dodd' seed within 80 days of being transferred to a greenhouse at 23C. Additional chilling reduced time and increased uniformity of budbreak. Different temperatures were not equally effective in satisfying chilling requirements, and the effectiveness of the various temperatures apparently changed during the rest period. This may indicate that severity of the winter may influence intensity of rest.

In the fall, families of seedlings in our orchards can be distinguished by the inception of dormancy, with seedlings from southern sources continuing growth later in the fall than seedlings grown from northen sources. The same observation has been made in black walnut (Bey 1971). Methods of evaluating this parameter need to be improved. Evaluation of leaf condition in the late season is subjective, and leaf drop is typically initiated after the first freeze. Since all seedlings drop leaves in a short period following the freeze, distinguishing differences is difficult. Since southern origin seedlings are more vigorously growing in the fall, they are more susceptible to fall freeze damage.

In addition to differences in timing the onset of winter dormancy, geographic regions should be distinguished on the basis of severity of winter freezes (Fig. 3). Families of open pollinated seedlings grown from 'Sioux' seed were more severely damaged than seedlings of 'Burkett' at inner scale split, and than seedlings of 'Curtis' at leaf burst (Grauke and Pratt 1992). This implies differences in levels of freeze hardiness that may be independent of phenology. Electrical conductivity of the solution in frozen samples has been used as a rough index of hardiness in dormant seedlings grown from various seedstocks (Hinrich, 1965). Seedlings from southern seedstocks such as 'Mahan' were apparently more susceptible to cold injury than were seedlings from northern stocks such as 'Posey', 'Major' and 'Giles'. Conductivity of solutions increased when samples were subjected to reduced temperatures (indicating greater injury), but the ranking of seedstocks did not change. Although hardiness of 'Burkett' and 'Riverside' seedlings were not compared directly, they were each compared to 'Mahan'. 'Mahan' seedlings were more hardy than 'Riverside', but less hardy than 'Burkett'. The difference in hardiness between 'Burkett' and 'Riverside' seedlings should be more accurately determined. Precision of rating freeze injury might be improved by modifying methods of Towill and Mazur (1975). They used 0.8% of 2,3,5-triphenyl tetrazolium chloride (TTC) in phosphate buffer (pH 7.5) applied to longitudinally cut stem sections to determine viability of the tissue.

PATTERNS OF SOIL AND PLANT VARIATION

Soils are complex, dynamic bodies formed by the integrated effects of climate and biotic activity acting on parent material in a given topography over time. Soils in the southeast have formed in a warm, humid climate, receiving abundant rainfall (Fig. 4). The plentiful rainfall leaches soluble bases and accumulates fine particles into lower strata. Over time, many soils have become acidic, with prominent clay zones (Fig. 5). The western U.S. generally receives much less rainfall (Fig. 4), allowing soils to retain high base contents and making them predominately alkaline (Fig. 5). The extreme northwest is an exception, receiving high winter rains, and having weathered, acidic soils, but pecan is not grown there.

Pecan is native to the Mississippi river and its tributaries from northern Illinois and southeastern Iowa to the Gulf Coast. Isolated populations occur as far east as southwestern Ohio, northern Kentucky and central Alabama, and as far west as the Edwards Plateau of Texas. That area encompasses a wide diversity of soils, from the well drained, alkaline soils of central Texas to the poorly drained cheniers of southern Louisiana (where hybridization with water hickory may be a factor in population survival). Preliminary evaluation of the genetic diversity of native pecans collected across that range indicates that western populations can be distinguished from eastern on the basis of isozyme allele frequencies (Grauke and Thompson 1994). Patterns of germination, growth, seedling size, and lateral root formation vary between seedstocks and are to some

extent related to population of origin. Whether those patterns of variation reflect adaptation to soil conditions remains to be determined. The variation in the soils supporting established native populations should be included as a factor in the selection of populations for screening in search of regional seedstocks.

Biotic activity in soils includes not only plant growth, but fungi and other microorganisms, such as nematodes. The wet, warm conditions of the southeastern U.S. are especially conducive to soil microorganisms. The role of fungi and nematodes should not be overlooked in assessing pecan rootstock performance. Several of the nurserymen surveyed noted reduced growth of seedlings if nursery sites were replanted to pecan. The extent of fungus and nematode involvement should be determined in such instances. Several species of nematode have been reported in association with pecan (Hendrix and Powell 1968, Grauke and Pratt 1985), with *Meloidogyne* species being most directly associated with pecan roots. Recovery of both galls and egg masses of *Meloidogyne* apparently differ between seedstock families (Grauke and Pratt 1985). Hendrix and Powell (1968) reported that the ring nematode [*Criconemoides quadricornis* (Kirhanova) Raski] and *Pythium irregulare* Buism.] were the most common soil microorganisms associated with pecan groves in Georgia. They reported that *Pythium spp*. reduced the root weight of container grown pecan seedlings up to 65%, compared to uninoculated seedlings. Poorly drained areas are more subject to *Pythium* infestation than well drained sites. Hsu and Hendrix (1973) studied the interaction of the ring nematode and two fungi [*Pythium irregulare* and *Fusarium solani* (Mart.l) App. & Wr.] on growth of pecan seedling roots. They found a marked reduction in root growth of 'Stuart pecan seedlings grown in soil infested with either fungus or with combinations of *Criconemoides* and fungi, but not where seedlings were grown in association with the nematode alone.

RECOMMENDATIONS

For nurserymen: Limited amounts of seed from local native pecan populations should be planted for comparison with standard seedstocks. To enhance selection of vigorous seedstocks, native populations in the vicinity of the nursery and to the south should be visited. For nurseries outside the native range of pecan, populations from the same temperature region (Figs. 2, 3) and similar soil group (Fig. 5) should be targeted. Initial selection within any prospective population should be on the basis of nut fill, since seedling growth has been shown to be related to percent kernel of seedstock (Grauke, 1991). At planting, seed should be kept separate by source tree in order to allow return to those with improved progeny performance. At digging, root condition of seedlings should be evaluated, with increased lateral root formation preferred. Seedstocks producing seedlings with maximum stem diameter are obviously preferred. If sales are targeted for regions receiving colder temperatures than the nursery site, seedstocks with increased hardiness should be used. This can be accomplished either by the use of native seed from the target region, or by the use of proven seedstocks for that area.

For pecan growers: Nursery stock should be purchased as close as possible to the orchard site, with attention paid to the seedstock used. Trees should not be purchased from nurseries located more than one temperature zone south of the orchard site (Fig. 3) unless trees are known to be on a hardy rootstock. Preliminary observations indicate that 'VC-168' will be an excellent rootstock for southwestern Arizona, but cold hardiness should be verified before it is relied upon in the elevated areas of southeastern Arizona. Until better information is available, the common eastern stocks should be used with caution west of Texas, while western stocks should be used with caution east of Texas. In the southeast, hybrid rootstocks should be preferred over water hickory and should be used only when site limitations dictate.

For researchers: Test orchards should control the variable of rootstock, either by using only one open-pollinated seedstock for rootstock production, or by incorporating multiple seedstocks as test variables. Test orchards should be established that bracket the known variability of rootstocks (on both east-west, and north-south axes), to allow increased resolution of rootstock effects. Methods of evaluating seedlings for chilling requirement and hardiness should be refined and applied to seedlings grown from known seedstocks, and to seedlings representing native pecan populations. Methods of evaluating the inception of dormancy in the fall should be developed. The role of nematodes and fungi on performance of seedling trees should be evaluated, in an effort to refine cultural control and select for resistance.

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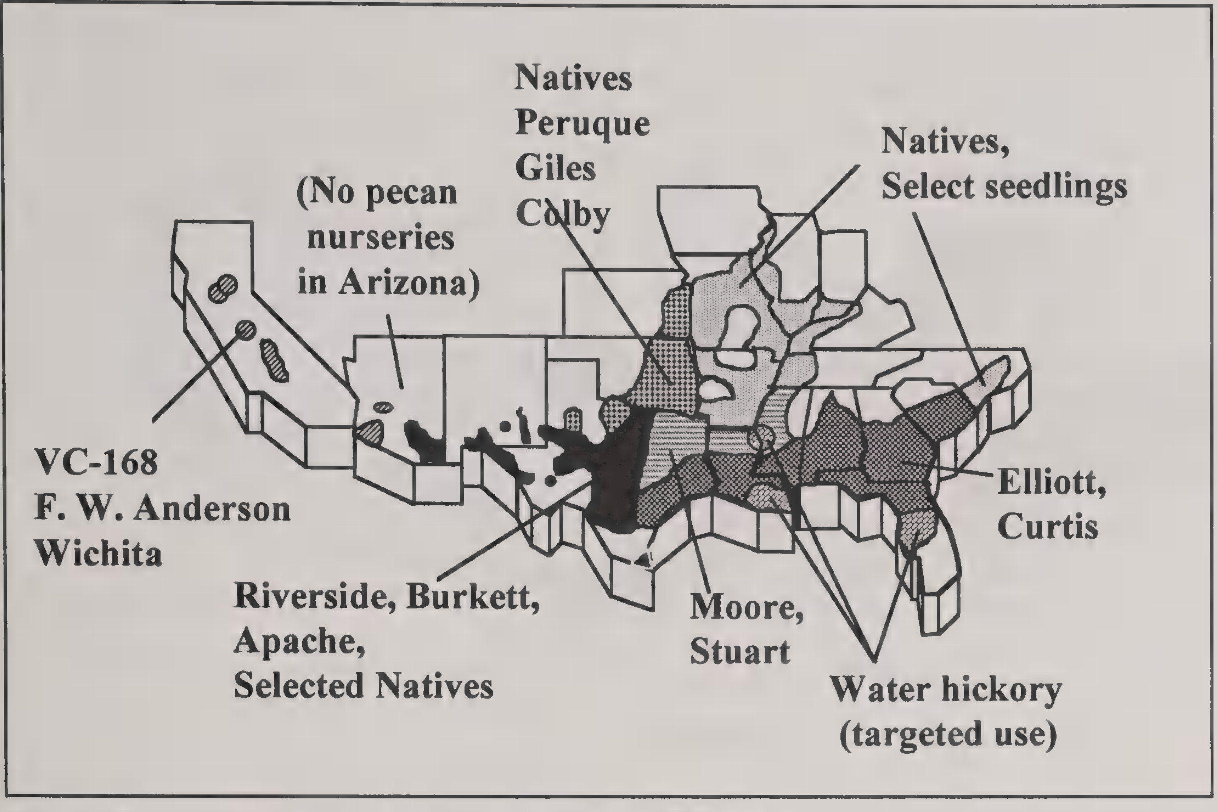

Figure 1. Seedstocks preferred by pecan nurserymen, based on 1994 survey.

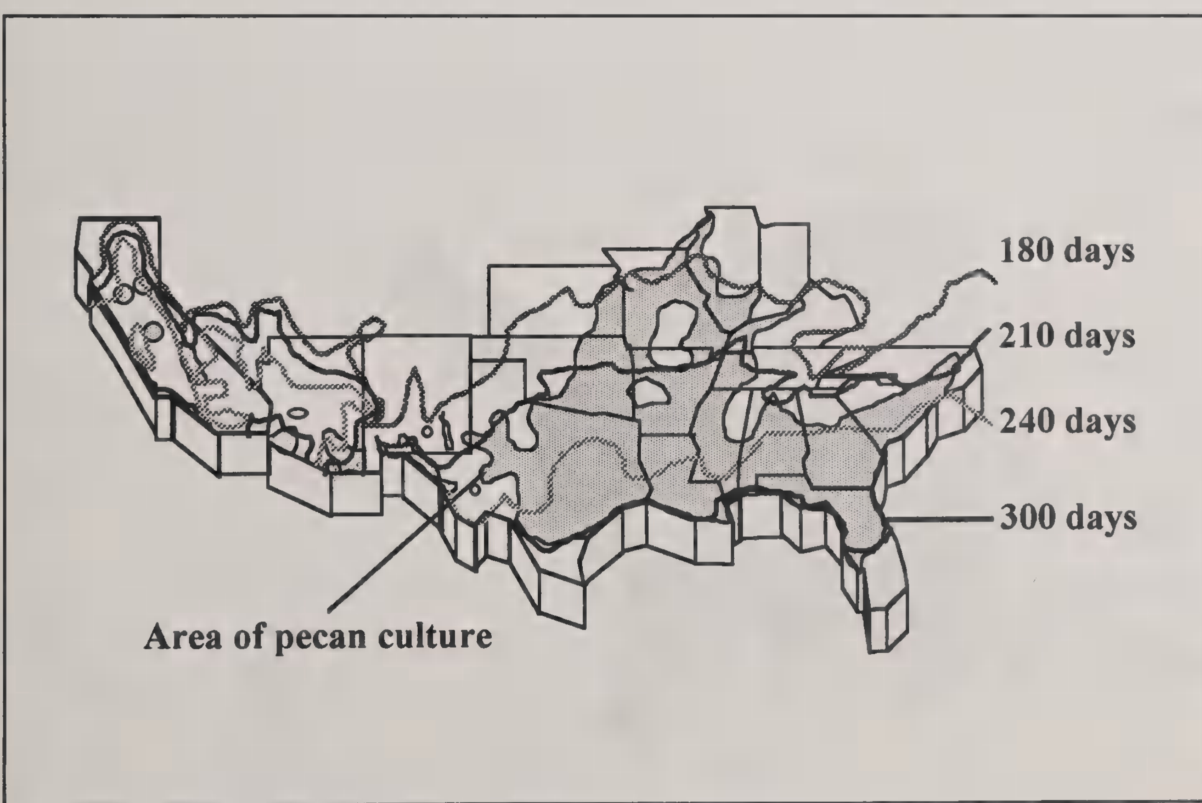

Figure 2. Mean length of freeze-free period, in days, for pecan growing areas of the United States. Adapted from Baldwin, 1975.

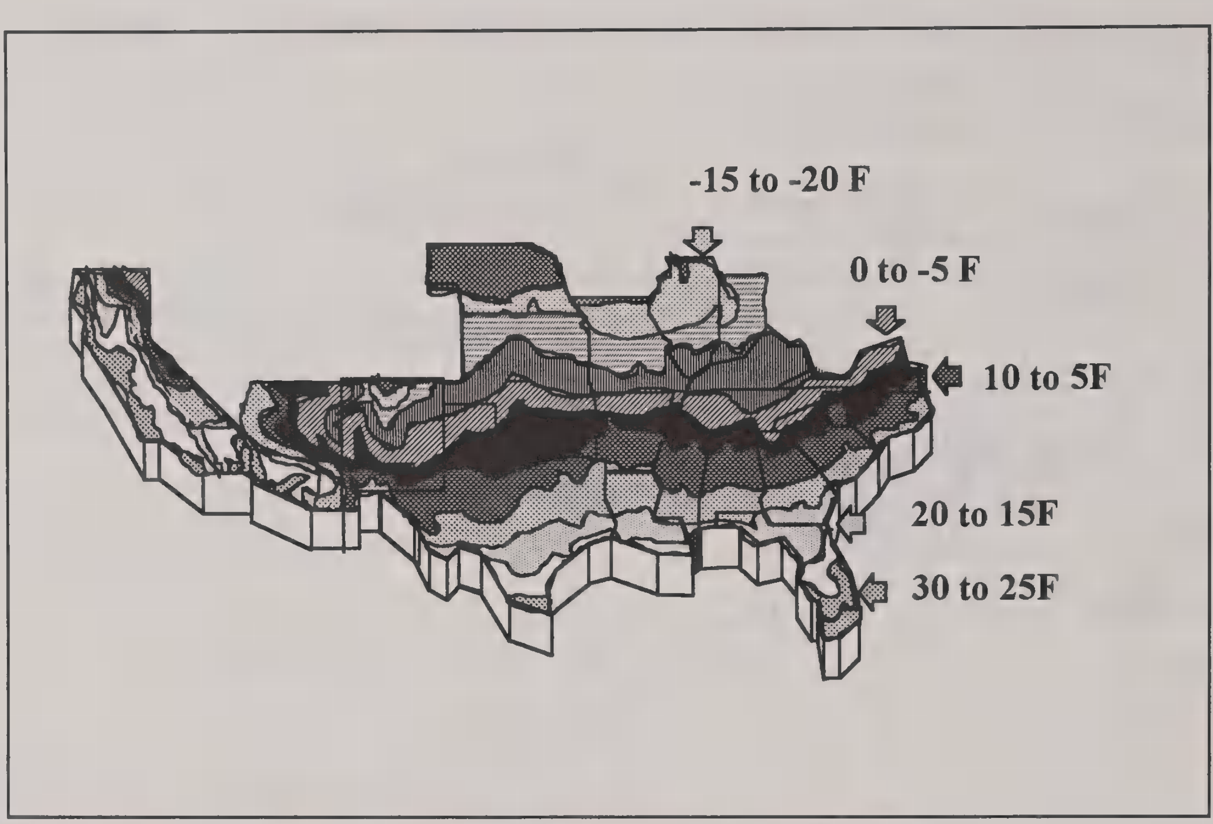

Figure 3. Average annual minimum temperature for pecan growing areas of the United States. Adapted from Cathey, 1990.

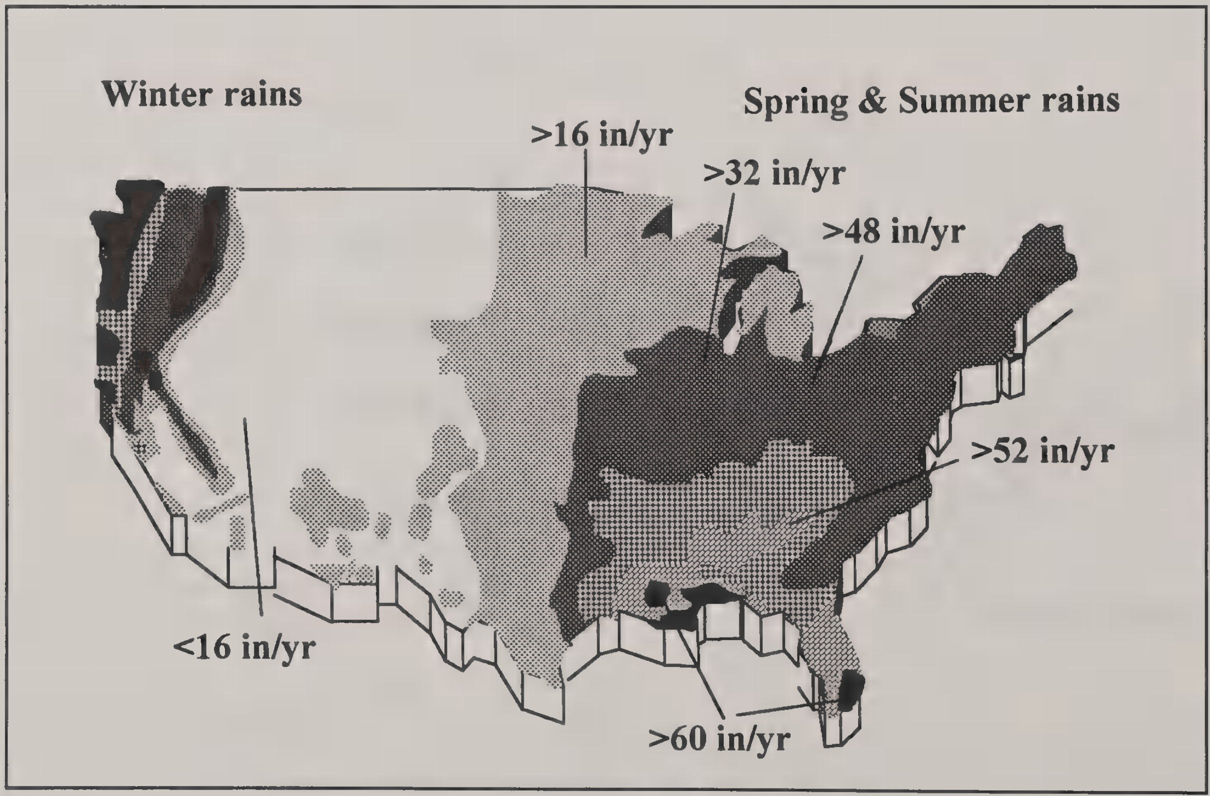

Figure 4. Normal total annual precipitation, in inches.Adapted from Baldwin, 1975.

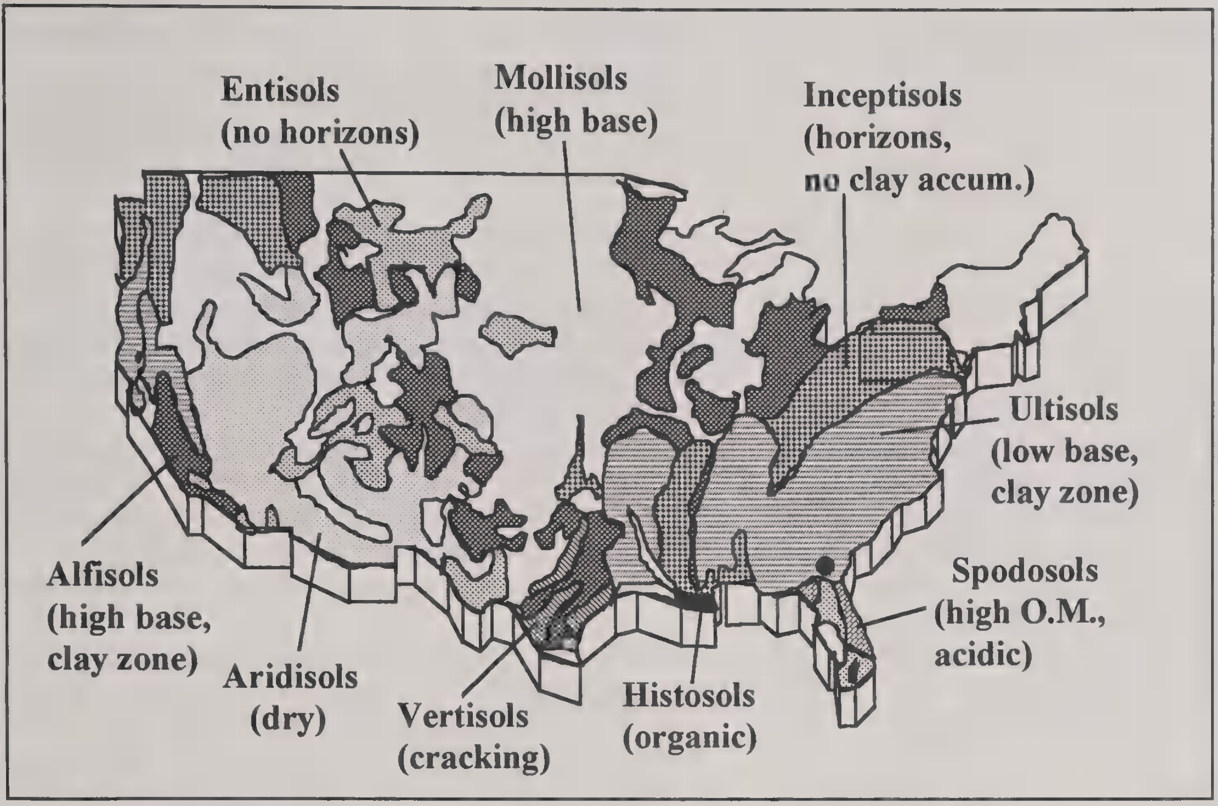

Figure 5. Patterns of soil orders and suborders in the United States. Adapted from Brady, 1974.

SUSTAINING NATIVE PECAN GROVES

W. Reid[1]

INTRODUCTION

Within the native range of *Carya illinoinensis*, conversion of riparian forest to productive native pecan groves has been practiced since the 1850's (Corsa 1898). When Europeans first began to settle in areas rich with native pecan, they conserved these food bearing trees while clearing other tree species for fuel wood and lumber (Flack 1970). Grazing animals were introduced to control understory vegetation and provide frontier families with milk, meat, and clothing. The integration nut tree culture with animal husbandry was not new to 19th-century settlers. Their native pecan groves were modeled after existing European silvipastoral systems cut from forests of Persian walnut (*Juglans regia*) or chestnut (*Castanea sativa*) (Smith 1929).

Today, the culture of native pecans remains a vital part of the U.S. pecan industry. Over the last ten years, the production of nuts from seedling pecan trees represented 30% of the nation's production (Fig. 1). Today's native pecan grove looks similar to those developed 100 years ago—cattle grazing under towering native trees. However, two major advancements, made during the 20th century, have allowed the native pecan silvipastoral system to remain viable; mechanized harvest and advanced pest management techniques. With these advancements, higher yields are harvested with greater efficiency.

Recently, the technologies that brought higher yields and greater efficiencies to both the pecan industry and all of agriculture are receiving close scrutiny (Francis and Youngberg 1990). Growing concerns about food safety, water quality, and the depletion of finite resources have prompted this reappraisal of current agricultural systems (USDA 1980). In response, the agricultural research community is placing an increasing emphasis on the development of new "sustainable" farming systems. Is native pecan culture sustainable? In this paper, I will review the current status of the native pecan agroecosystem and discuss the potential for sustaining native pecans in the future.

NATIVE PECANS: A MODEL FOR SUSTAINABLE AGRICULTURE

Low-input, perennial crops, genetically diverse, and multicropping are all words that can be used to describe the native pecan system. These words are also key terms used in designing sustainable agricultural systems. A closer look at the native pecan system will reveal that the native pecan grove should be held up as a model system for sustainable agriculture.

The Native Pecan Agroecosystem

Native pecan groves are developed from an existing, indigenous plant resource. In areas where pecan is endemic, bottomland timber areas are cleared of all competing woody species and the remaining pecan stand is thinned to allow optimum light penetration. A permanent cover of grasses and/or forbs are allowed to grow under the trees protecting the soil from the erosive force of river flood waters. Grazing animals, usually cattle, are introduced to control the vegetative growth of the ground cover.

Upon release from the forest, native pecan trees begin bearing nuts almost immediately, with full production usually occurring in 4 to 5 years (Reid and Olcott-Reid 1985). However, increased nut production provides ample food supplies for nut feeding insects and populations of these pests soon increase to economically damaging levels. Currently, native pecan producers make 3-5 insecticide applications per year to keep these pests in check. Management of insects and diseases in native pecan groves is not entirely based on chemical controls. As native groves grow, additional trees must be thinned from the orchard to preserve optimum light penetration. During this thinning process, trees demonstrating severe reactions to disease and/or insects can be removed. This simple process of genetic selection can significantly cut production costs. A detailed review of this low-input approach to native pecan pest management has been given (Reid and Eikenbary 1991).

The native pecan silvipastoral system produces three crops; pecans, pecan wood products, and cattle. Costs of production for these crops include many of the normal costs associated with modern agriculture, such as; machinery, fuel, pesticides, and labor. However, the hidden costs of soil loss and nonpoint surface water pollution usually associated with row crop agriculture are minimized in native pecan groves. Soil erosion is curtailed in the native grove by the presence of both the trees and perennial ground cover. In some locations, pecan groves actually have a net soil gain following flooding events. In addition, native pecan orchard soils have high organic matter levels developed from decomposing pecan leaves, groundcover leaves and roots, and animal manures. High soil organic matter content is an effective buffer against the movement of nonpoint pollutants (Ingels 1994). In fact, tree planting adjacent to streams and rivers has been recommended as an effective method for improving rural water quality (Welsch 1991).

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Sustainability

Much of the literature concerning sustainable agriculture is devoted to a debate over definitions (Lehman, Clark, and Weise 1993). However, the goals of many sustainable systems are to reduce off-farm inputs, preserve the natural resource base, and maintain economic productivity. Within this context, it is easy to see that the native pecan system may be the most sustainable form of agriculture practiced in many river floodplains. Managing an existing and perennial plant resource (pecans) rather than the annual planting of agronomic crops have many benefits. The native pecan system is often more profitable than agronomic crop production (Reid and Olcott-Reid 1985) and strategies for reducing inputs have been devised (Reid and Eikenbary 1991). In addition, the pecan system enhances both soil and water resources as mentioned above.

Are native pecan groves sustainable? Silvipastoral systems have been sustained for centuries (Smith 1929) and the native pecan system has been practiced for over 100 years (Corsa 1898). The sustainability of these systems are documented by their longevity. In addition, native pecan groves meet many of the criteria set by today's sustainable agricultural movement (Stockle et al. 1994). These criteria include: profitability, productivity, preservation or enhancement of soil, air and water resources, low inputs, efficient use of biological resources, and enhancement of rural communities.

Setting Management Priorities

Native pecan production has received little attention from the agricultural research community. It is interesting to note that even in the early part of this century, when native pecan dominated the marketplace, native grove management was mentioned in major pecan culture texts only in passing (Reed 1912, Stuckey and Kyle 1925). Even in Texas, a major native pecan producing state, the 1912 bulletin entitled "The Pecan In Texas" discusses native pecans only in reference to methods for topworking (Burkett 1912). A notable exception has been the work of Herman Hinrichs, who established guidelines for optimum tree densities in a native groves (Hinrichs 1958). Yet, given all this inattention, native pecan producers have continued to thrive by borrowing technologies developed for orchards of improved varieties.

Although many aspects of native pecan management are similar to those used to manage orchards of improved cultivars, the native system has enough unique qualities to justify the development of unique production strategies. The most significant native pecan production problem is one of misplaced priorities. Currently, the management approach taken by many native pecan growers is to let nature determine the nut cropping potential of their trees. If a good crop is set, then large investments in pesticide applications and orchard floor maintenance are made to protect the nuts and ease harvest. If the trees do not set a good crop of pistillate flowers, then operators turn out the cows and forget the about the trees. With this management approach, many native groves have become overcrowded and nut production has steadily declined and become more erratic.

Nut production is the most profitable portion of the native pecan silvipastoral system. Growers should be encouraged to reorder their management priorities and put nut production first. Regular production of high quality nuts is only possible from healthy trees that receive optimum sunlight. Investments in tree thinning, surface drainage, and nitrogen fertilization stimulate nut production and increase tree vigor (Reid and Olcott-Reid 1985). Only after a grower develops fruitful trees, should investments be made into pest control. Cattle grazing in a native pecan should be viewed solely as a labor saving measure used to reduce the costs of mowing the groundcover. A recent study of the returns from cow-calf operations reveals a net return of only $21.15 per acre (Fausett and Langemeier 1991). In Table 1, the management priorities of a typical native pecan grower are contrasted with the priorities that should be held based on economic returns.

THREATS TO SUSTAINABILITY

As mentioned earlier, the native pecan silvipastoral system is a prime example of a sustainable agricultural system. The future sustainability of this system is largely dependent on how well producers can adapt to three man-made problems currently influencing the industry.

Price Fluctuations

The amount of investments landowners make in managing native pecan groves is largely determined by expected returns from pecan sales. During the period of 1974 to 1989, the prices paid for native pecans varied with crop year but remained relatively constant (Fig. 2). But recently (1992), native pecan prices reached an all time high before crashing during the 1993 cropping year (Fig. 2). During this brief period of high prices, interest in native pecan management soared with many formerly abandoned acres being brought back into production. However, the extremely low prices paid for native pecans in 1993 did not even cover the costs of production. These events left many landowners worried about future pecan prices and overly cautious about investing in the inputs needed to properly manage native groves. If the native pecan system is to remain sustainable, growers must be confident that they can reap profits from their investments. The likely prospect of long term profits is a prerequisite for growers to make long term investments in tree thinning, surface drainage, and fertilization.

The Clean Water Act

The 1985 Clean Water Act was enacted to help preserve our nation's water supply. Within this legislation, provisions were made to protect America's wetlands because of their importance as biological water filtering systems. The delineation of wetlands in agricultural areas has become very controversial and is largely responsible for the current personnel property rights movement. Four federal agencies have claimed jurisdiction over the wetlands issue; the USDA Soil Conservation Service, the US Fish and Wildlife Service, the Environmental Protection Agency, and the US Army Corps of Engineers. This massive bureaucracy associated with wetlands issues has lead to much confusion and to a myriad of wetland definitions (Lyon 1993). Understanding the wetlands issue is critical for native pecan producers because many of their groves are located in wetland areas. In fact, in some pecan producing states, pecan is listed on the national list of plant species that occur in wetlands as a facultative wetland species (estimated probability of .67 to .99 that the presence of pecan trees indicates the site is a wetland) (Reed 1988). In addition, many of the soils that support natural populations of pecan trees are listed as hydric soils (USDA 1987). Currently, the presence of a hydric soil and plants native to wetlands are the primary evidence used to delineate wetlands (Lyon 1993).

But how does the determination that a native pecan grove occurs in a wetland effect the sustainability of the pecan silvipastoral system? Currently, the removal of trees and the cutting of drainage ditches in a wetland is in violation of the Clean Water Act. As mentioned earlier, these two activities are critical for stimulating nut production from native pecan trees. Today, landowners must apply to the SCS for a Section 404 exemption to the Clean Water Act and prove that their planned activities (native pecan management) have a minimum impact on the wetland. This process often takes over six months and is becoming an effective deterrent to new grove development. When the Clean Water Act is rewritten in 1995, it is our responsibility to ensure that the management of native pecans is promoted as a form of agriculture that can protect and preserve our riparian environments. If additional restrictions are placed on the utilization of wetland sites in the 1995 law, then the sustainability of the native pecan system may become threatened.

National Water Management Priorities

The movement of grain, coal, and other industrial goods in barges along inland waterways has become vital to the economies of many midwestern states. Control of these waterways and all water that flows into these navigable channels has been assigned to the US Army Corps of Engineers (USACE). During the 1950's and until the early 1970's, the USACE built massive water projects throughout the Mississippi River drainage system. USACE constructed lakes were billed by local congressmen as beneficial flood control projects that would also bring recreation and tourism dollars into the local economy. The USACE views these projects as water storage facilities used to regulate the flow of water down inland waterways.
Lakes, levies, canals, dams and locks have all had a major impact on riparian vegetation including pecan trees. To protect shipping interests, the release of flood waters from major USACE lakes have be slowed causing upstream flooding to become magnified. Over the past 3 years, thousands of acres of native pecan groves in Kansas, Missouri, and Oklahoma have been inundated by back water from major lakes. Although flooding is a natural part of the pecan agroecosystem, the current water management practices of the USACE have resulted in extending the duration of flooding events and raising the water table. Massive native trees, many over 100 years old, have been killed in recent years by excessive flooding and soil saturation. It is important to note that, in the northern most portion of pecan's natural range, pecan trees are dying, not from cold temperatures, but from an artificially elevated water table along the Mississippi river, 50 miles south of Dubuque, IA. Will the loss of this important germplasm resource be noted by conservationists?

USACE induced flooding is not a new problem. Fred Brison spoke to the Texas pecan growers association about this very problem 16 years ago (Brison 1978). Today, flooding problems continue and native pecan producers feel their future is in the hands of a federal agency which is not accountable to anyone. However, federal water management policies can be changed. Recently, a group of property owners along the Neosho River (including native pecan producers) were successful in lobbying senators in Kansas and Oklahoma to form a congressional committee to study the impacts of current water management practices. This committee will formulate a new water management policy that will address the concerns of property owners along the river.

The problems associated with USACE water management policies vary with each watershed. However, native pecan producers across the country should become involved in the political processes that shape these policies. If the concerns of pecan growers are not heard, government officials assume their policies are not causing serious problems.

CONCLUSION

Native pecan growers raise a wholesome product using environmentally friendly production practices. The native pecan silvipastoral system should be heralded as a model for sustainable agriculture. The culture of native pecans will continue to be a profitable as long as the demand for topper halves remains strong and excessive environmental regulations are not implemented.

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Table 1. Management priorities of the typical native pecan producer vs. priorities based on economic returns.

Priorities Set By Typical Grower	Priorities Based On Economic Returns
1. Insect Control	1. Tree Thinning
2. Grazing	2. Surface Drainage
3. Tree Thinning	3. N Fertilization
4. Disease Control	4. Insect Control
5. N Fertilization	5. Disease Control
6. Surface Drainage	6. Grazing

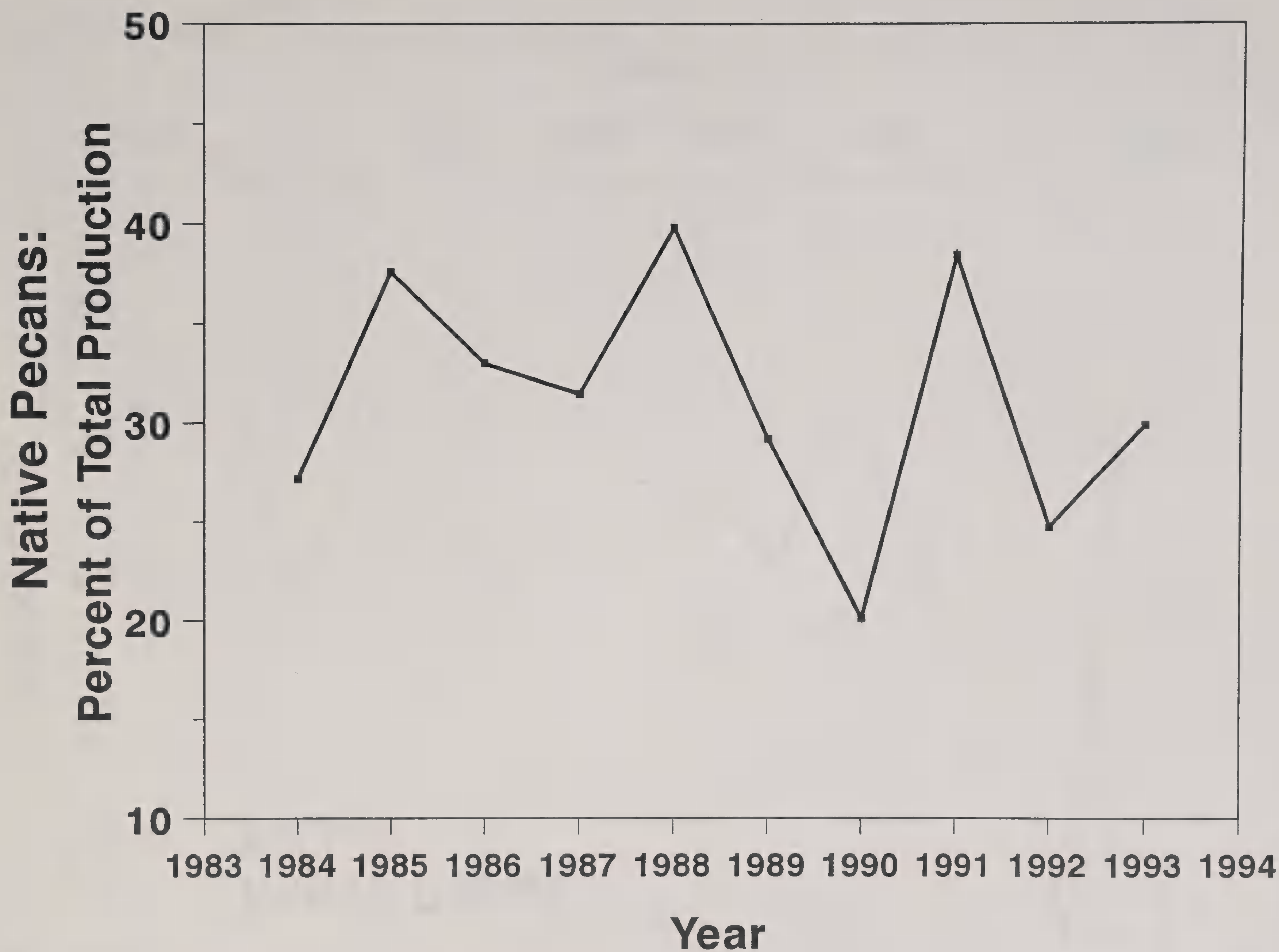

Figure 1. The percentage of total US pecan production harvested from seedling pecan trees from 1984 to 1993. (Source USDA ERS)

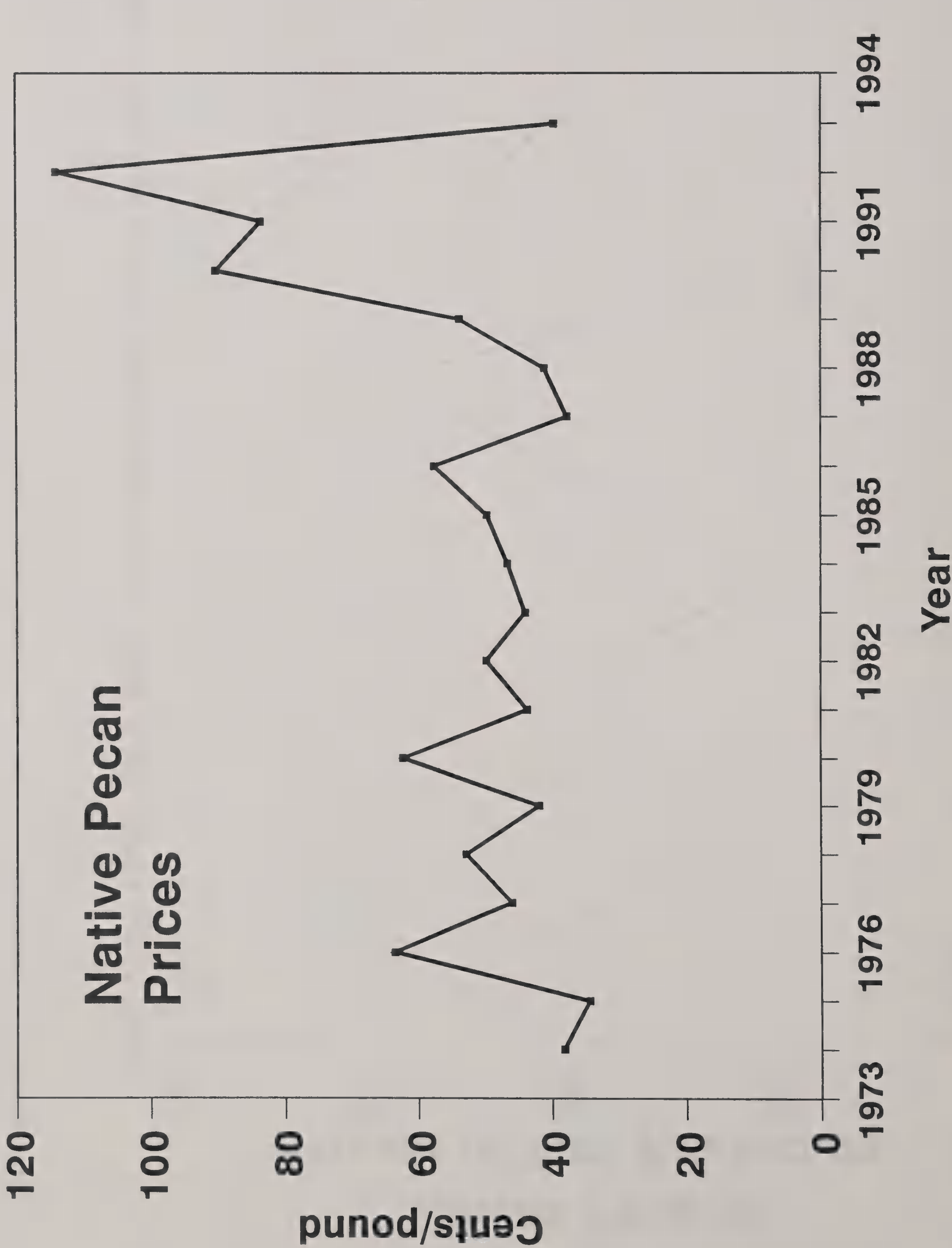

Figure 2. Average price paid for seedling pecans from 1974 to 1993. (Source USDA ERS)

ORCHARD FLOOR CROPS AFFECT GROWTH OF YOUNG PECAN TREES

W.G. Foshee[1], W.D. Goff[1], M.G. Patterson[2] and D.M. Ball[2]

Growing cover crops in mature pecan orchards has been practiced for several years. In fact, research in Alabama in the 1950's showed that orchards that had legumes yielded more than those without legumes. In recent years, the emphasis of growing cover crops has shifted to increasing predatory insects for aphids suppression. No data has been gathered to document the effects of covers on growth for young pecan trees. Therefore, the purpose of our study was to determine if growing cover crops underneath young pecan trees had a positive or negative affect on growth. Winter and summer legumes, along with perennial grasses and nutsedge were grown underneath young 'Desirable' pecan trees for two years. In addition, a weed free treatment was maintained with herbicides.

The cover crops were: hairy vetch [*Vicia villosa*], common vetch [*Vicia sativa*, 'Cahaba White'], arrowleaf clover [*Trifolium versiculosum*, 'Yuchi'], crimson clover [*Trifolium incarnatum*, 'Tibbee'], red clover [*Trifolium pratense*, 'Redland II'], yellow nutsedge (*Cyperus esculentus* L.), buckwheat (*Fagopyrum sagittatum*), hairy indigo (*Indigofera hirsuta* L.), bahiagrass [*Paspalum notatum*, 'Pensacola'], common bermudagrass [*Cynodon dactylon* (L.) Pers.], and centipedegrass (*Eremochloa ophiuroides*). The weed free treatment was maintained using a preemergence application of oryzalin [4-(dipropylamino)-3,5-dinitrobenzenesulfonamide] plus norflurazon [4-chloro-5-(methylamino)-2-(3-(trifluoromethyl)phenyl)-3(2H)- pyridazinone] plus glyphosate [N-(phosphonomethyl)glycine] at a rates of 2.2, 2.8, and 1.7 kg ai.ha^{-1}, respectively in March of each year. This was followed with two applications of glyphosate [N-(phosphonomethyl)glycine] at a rate of 1.7 kg ai.ha^{-1} during June and August of each year.

All cover crops suppressed tree growth during this two year study. There were no differences among the cover crops. The weed free plots were significantly larger than any grown with a cover. Mean caliper of weed free trees increased 224 percent during the two year period compared to 123 percent for trees grown with cover crops.

We feel that the results of our study do not detract from the desirability of growing cover crops in pecan orchards, but displays the need to grow cover crops in row middles, away from the rooting zone of very young trees.

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PECANS AND HUMAN HEALTH

C.R. Dove[1], R.E. Worley[1] and S.K. Dove[1]

Current dietary recommendations are that humans should consume diets that contain less than 30% of the energy (calories) from fat (American Heart Association, 1986; National Institutes of Health, 1984) This is considerably lower than the diets containing 36 to 37% of energy from fat, that are currently being consumed by the average adult in the U.S. (National Research Council 1988). It is also recommended that saturated fatty acid intakes be reduced from the current level of 13 to 14% of the energy in the diet to 10% or less of the energy in the diet (American Heart Association 1986). Most individuals in the U.S. have a very difficult time meeting these guidelines. Several nutritionists feel that it is not necessary to eat a low fat (20 to 30% of energy) diet to obtain optimal benefits to serum cholesterol concentrations (Berner 1993). A monounsaturated fatty acid rich diet with 30 to 35% of the energy from fat elicits a similar response as long as saturated fatty acid intakes account for 10% or less of the energy (Berner 1993). The fatty acid profile of pecans make them an ideal part of a diet meeting these specifications.

The amount of fat and the type of fat consumed in the diet are significant factors influencing the health and nutritional status of individuals. High levels of serum lipids and serum cholesterol are associated with increased incidence of ischemic heart disease, strokes, atherosclerosis and obesity (Zapsalis and Beck 1985). Generally, consumption of saturated fatty acids is associated with increases in serum cholesterol and lipid levels, while consumption of monounsaturated and polyunsaturated fatty acids are normally considered cholesterol neutral or cholesterol reducing (Kaare 1992). Recent studies have shown that the amount of the individual fatty acids in the diet may be more important than the classification of the fatty acid. Saturated fatty acids with 12, 14 or 16 carbons have been found to increase the serum cholesterol levels the most, primarily through increases in LDL cholesterol (Grundy and Denke 1990). Increased levels of LDL cholesterol are normally highly correlated with increased risk of coronary heart disease (Zapsilis and Beck 1985). Stearic acid (C18:0) has been shown to be cholesterol neutral and does not increase plasma LDL cholesterol levels like other saturated fatty acids (Keys et al. 1965, Bonanome and Grundy, 1988). Most of the monounsaturated fatty acids, and especially oleic acid (C18:1) have been shown to be as effective in reducing serum cholesterol and lipid levels as the polyunsaturated fatty acids (Mattson and Grundy 1985, Grundy, 1986, Mensink and Katan, 1989).

Fats and oils derived from plants normally contain a higher concentration of unsaturated fatty acids (on a % basis) than do fats and oils derived from animals, and therefore fats and oils from plants are considered healthier for humans. Within the plant kingdom, there is a wide variation in the composition of the fats and oils. The fatty acid composition of several common animal, plant and nut fat or oils are shown in Table 1 and the fatty acid composition of several varieties of pecans is shown in Table 2. On the average, over 90% of the fatty acids in pecans are unsaturated, with over 64% of the oil being oleic acid. These values are very comparable to the fatty acid composition of canola oil, olive oil, and almond oil, all of which have been associated with heart healthy diets.

Recent studies with walnuts (Sabate et al. 1993) have indicated that total, LDL and HDL cholesterol in healthy men were reduced when 20% of the calories in the diet were supplied by walnuts. In this study walnuts replaced other fat sources so that the caloric density of the walnut diet and the control diet were similar. Walnuts have a similar level of total unsaturated fatty acids as pecans. However, the level of monounsaturated fatty acids is much lower in walnuts than in pecans and the level of polyunsaturated fatty acids is much higher.

There are numerous physiological and metabolic similarities between pigs and humans. Pigs are similar to humans in dental characteristics, renal morphology and physiology, eye structure, skin morphology and physiology, cardiovascular anatomy and physiology, and digestive anatomy and physiology (Pond and Houpt 1978). Genetic and environmental differences can be easily controlled and variation across animals can be minimized. Cholesterol metabolism is similar in pigs and humans, and pigs have been successfully used numerous times to study cholesterol synthesis, retention and the effects of diet on cholesterol metabolism (Faidley et al. 1990, Beynen et al. 1990, Diersen-Schade et al. 1986, Marsh et al. 1972).

An evaluation of the fatty acid composition of pecans indicated that pecan oil should have a serum cholesterol lowering effect when included in the diet. Therefore a series of trials was initiated to evaluate pecan oil as a source of dietary fatty acids. The objective of the first trial was to determine if pecans could be included into swine diets and to evaluate the effect of adding fat to the diet on serum cholesterol and triglycerides.

The first trial utilized 48 crossbred pigs (24 castrate males and 24 females) over a 35 day period. Pigs had an average initial weight of 19.8 ± 1.2 kg. The trial was terminated at 35 days due to a lack of available pecans to extend it further. Pigs were allotted by weight and sex and assigned to one of

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4 dietary treatments. Pigs were housed in individual pens in a modified open front building with ad libitum access to feed and water.

The treatments in this trial were 1) standard corn-soybean meal control diet; 2) corn-soybean meal diet with 6% animal fat; 3) corn-soybean meal diet with 6% soybean oil; 4) corn-soybean meal diet with 9.4% pecans (equivalent to 6% pecan oil). All diets were formulated to contain 15% crude protein. The control diet contained 7% of the dietary calories from fat, and the added fat and pecan diets provided 18.6% of the calories from fat. These values are lower than the current levels of calories from fat in human diets, but were the maximum practical in this type of study. Vitamins, minerals and other nutrients were added to meet or exceed the 1988 NRC requirements. The composition of the experimental diets is shown in Table 3. A blood sample was collected, following a 12 hr fast, on days 1, 14, 28 and 35 of the trial for serum cholesterol and triglyceride analysis.

Data was analyzed as a randomized complete block with repeated measures using SAS (1985) GLM. The initial bleed values for cholesterol and triglycerides were used as a covariant for analysis of the respective data.

Growth data from this trial indicates that pigs fed diets containing pecans have similar growth performance as pigs fed other fat sources (Table 4). All pigs fed the added fat diets tended to grow faster than pigs fed the no-fat control diet ($P < .08$). This is consistent with the data from other research trials feeding fat to pigs of this age (Keaschall et al. 1983). Numerically, pigs fed the pecan diets had decreased performance compared to the pigs fed the other fat sources. This is probably due to the amino acid composition of the pecans. Based on reported values for pecans (Wood and Reilly 1984, Elmore and Polles 1980), pecans appear to be low in methionine, threonine, and leucine compared to other protein sources normally included in swine diets. No attempt was made to balance the diets for these amino acids.

Serum cholesterol values were extremely variable over the course of the study, however they tended to decrease as the trial progressed (Table 4). Serum cholesterol levels were lowest on day 28 of the trial in those pigs fed the added fat or pecan diets and then were increased on day 35. While the feeders were removed from the pens 12 hours before the blood samples were taken, to simulate a fast, residual feed in the pen may have contributed to the variability of the cholesterol values. Overall, serum cholesterol levels were not affected by any of the dietary treatments in this study. Considering the short duration of this study and the young age of the pigs, these results were not unexpected. It should be noted that the diets used in these studies contained no added cholesterol and therefore, cholesterol intake was extremely low.

Serum triglyceride values also decreased from day 1 to day 14, but then remained relatively stable for the duration of the trial (Table 4). On day 35 of the trial, serum triglyceride levels in those pigs fed the control diet had decreased the most, while pigs fed the pecan diet were intermediate and those pigs fed the oil diets had the highest serum triglyceride levels ($P < .01$). In swine, decreases in serum triglyceride levels have been found to be important in assessing the atherosclerotic status (Agarval and Arora 1973). The data from this study would suggest that oil from pecans has less of an effect on raising serum triglyceride levels than do soybean oil or animal fat.

Overall, the data from this study indicates that pecans can be consumed by pigs at moderate dietary levels with no adverse effects on growth. The inclusion of the pecans in the diet did not effect total serum cholesterol levels, but did numerically reduce serum triglyceride levels compared to the other fat sources used in this trial. These data indicate that pecans have the potential to have a positive effect on serum lipid levels when consumed in moderate quantities by swine.

An additional study using pregnant swine has been initiated. In this study the effects of the inclusion of pecans in the gestation diet is being evaluated compared to a no-fat diet and a diet containing animal fat. The diets in this study have been supplemented with cholesterol, such that total dietary intakes of cholesterol are 200 mg/d.

Hopefully the results of this longer term study will show if pecans have an effect on serum cholesterol levels.

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Table 1. Composition of animal and plant fats and oils.

Fat source	Fatty acids % of total fat											
	≤ C15:0 + C17:0	C16:0	C16:1	C18:0	C18:1	C18:2	C18:3	≥C:20	SFA[a]	MUFA[a]	PUFA[a]	TUFA[a]
Tallow[b]	7.4	25.5	3.4	21.6	38.7	2.2	.1	.6	54.5	42.1	2.9	45.0
Lard[b]	2.7	24.8	3.1	12.3	45.1	9.9	0	2.0	39.8	48.2	11.9	60.1
Butterfat[b]	26.6	26.2	1.9	12.5	28.2	2.9	.5	.3	65.3	30.1	3.7	33.8
Canola[c]	.1	4.0	.2	1.8	59.7	22.9	10.6	.7	5.8	59.9	34.2	94.1
Corn[c]	.1	11.4	.1	2.1	27.9	56.9	1.1	.4	13.6	28.0	58.4	86.4
Olive[c]	.1	11.0	.9	3.3	75.7	7.9	.6	.4	14.4	76.6	8.9	85.5
Peanut[c]	.1	11.2	ND[d]	2.6	52.6	31.7	.3	1.6	13.9	52.6	33.5	86.1
Safflower[c]	.1	6.6	.1	2.0	12.0	78.5	.2	.6	8.7	12.1	79.2	91.3
Soybean[c]	.2	10.8	.1	4.1	24.8	52.9	6.7	.4	15.1	24.8	60.0	84.8
Sunflower[c]	.1	6.5	.1	4.7	20.6	67.0	.1	.3	11.3	20.6	67.4	88.0
Almond[c]	.1	6.6	.5	1.2	69.8	21.6	ND[d]	.1	8.0	70.3	21.7	92.0
Cashew[c]	.2	9.7	.3	7.5	61.3	20.2	.2	.7	17.3	61.6	21.1	82.7
Pistachio[c]	.1	11.8	1.1	1.4	54.3	30.5	.6	.2	13.3	55.4	31.3	86.7
Black Walnut[c]	.1	7.6	.1	2.5	17.7	58.6	13.3	.1	10.1	17.8	72.1	89.9
Pecan[c]	.1	5.9	.1	2.3	64.7	25.5	1.1	.2	8.3	64.8	26.9	91.7

[a] SFA=Saturated Fatty acids; MUFA=Monounsaturated Fatty Acids; PUFA=Polyunsaturated Fatty Acids; TUSA=Total Unsaturated Fatty Acids.
[b] Taken from Zapsalis and Beck. 1985. Food Chemistry and Nutritional Biochemistry. John Wiley and Sons, New York. p. 426.
[c] Adapted from Worley and Dove, unpublished data.
[d] Not detected.

Table 2. Average fatty acid composition of various pecan varieties over 3 years.[a]

Pecan variety	≤ C15:0 + C17:0	C16:0	C16:1	C18:0	C18:1	C18:2	C18:3	≥C:20	SFA[b]	MUFA[b]	PUFA[b]	TUFA[b]
Cape Fear	.1	5.9	.1	2.4	66.3	23.8	1.1	.2	8.4	66.3	24.9	91.2
Desirable	.1	5.6	.1	2.2	67.1	23.5	1.3	.2	7.9	67.2	25.0	92.2
Stuart	.2	6.3	.1	2.2	61.1	28.8	1.3	.2	8.6	61.2	30.3	91.5
Sumner	.1	6.5	.1	2.2	63.4	26.6	1.0	.2	8.8	63.5	27.7	91.2
Western Schley	.1	6.0	.1	2.7	64.3	25.3	1.3	.2	8.9	64.4	26.8	91.2
Avg. of ~ 100 varieties	.1	5.9	.1	2.3	64.7	25.5	1.1	.2	8.3	64.8	26.9	91.7

[a] Worley and Dove, unpublished data.

[b] SFA=Saturated Fatty acids; MUFA=Monounsaturated Fatty Acids; PUFA=Polyunsaturated Fatty Acids; TUSDA=Total Unsaturated Fatty Acids.

Table 3. Composition of experimental diets, %.

	No-fat Control	Animal fat	Soybean oil	Pecan
Corn	80.5	73.3	73.3	72.4
Soybean meal, 48% CP	16.6	17.9	17.9	15.3
Oil	——	6.0	6.0	——
Pecans[a]	——	——	——	9.4
Dicalcium phosphate	1.1	1.1	1.1	1.2
Limestone	.9	.8	.8	.8
L-lysine	.3	.3	.3	.3
Salt	.2	.2	.2	.2
Trace mineral mix	.1	.1	.1	.1
Vitamin mix	.2	.2	.2	.2
Ethoxyquin.1	.1	.1	.1	
Calculated composition				
Crude protein, %	15.0	15.0	15.0	15.0
L-lysine, %	.95	.95	.95	.95
Met. energy mcal/kg	3.22	3.50	3.50	3.45
Calcium, %	.62	.62	.62	.62
Phosphorus, %	.50	.50	.50	.50

[a] Pecans were analyzed to contain 13.75% crude protein, 62.69% fat, .18% Ca, and .27% P.

Table 4. Effects of dietary fat supplementation on the growth performance and serum lipids of growing pigs.[a]

	Control	Animal fat	Soybean oil	Pecans	SE
Daily gain,	832[b]	943[c]	931[c]	882[c]	30
Daily feed intake, g	2368	2469	2457	2422	83
Gain/feed, g/kg	352	383	380	366	10
Total serum cholesterol, mg/dl					
Day 1	136	138	144	143	
Day 14	96	105	101	107	14.4
Day 28	151	101	96	106	14.4
Day 35	105	119	113	128	14.4
Serum triglycerides, mg/dl					
Day 1	94	100	85	102	
Day 14	43[d]	58[d]	72[e]	48[d]	6.4
Day 28	47[d]	70[e]	61[de]	65[e]	6.4
Day 35	44[d]	67[e]	67[e]	56[de]	6.4

[a] 12 pigs/trt, initial weight 19.8 kg.
[bc] Means with different superscripts differ P < .08.
[de] Means with different superscripts differ P < .01.

PECAN INDUSTRY IN THE WESTERN U.S.

M.W. Kilby[1] and E.A. Herrera[1]

Even though pecans are not native to the western region of the U.S., commercial pecan orchards and processors are active and abundant. The western region could be defined as the area where pecans are grown and have to be irrigated for optimum tree growth and maximum production. The major states which compose this region are Arizona, California, New Mexico and Far West Texas. Currently, there are approximately 50,000 acres of improved varieties planted in these states at various densities (12-96 trees per acre) with a primary spacing of 30'x 30' or 48 trees per acre. New Mexico leads the pack with 21,000 acres followed by Arizona (14,500), Far West Texas (12,000), and California (3,500). There are a few scattered planting in Southwestern Utah and Nevada. At this time this region has a potential production of 62 million pounds. In all likelihood the production will increase as most orchards are grown under intensive management. Average annual production for each state has developed the following trend: New Mexico = 27 million pounds., Arizona = 14 million pounds, Far West Texas = 12 million pounds, California = 3 million pounds.

As we review the history of the Western region it becomes apparent that the focus of commercial planting was in and around the Rio Grande River Valley. The first plantings were established at New Mexico State University as early as 1914 with Stahman Farms being initially planted in 1934 near Las Cruces, NM. The early success of Stahman Farms lead to the establishment of commercial planting in the 1960's in Arizona, Far West Texas and the major acreage in the 1970's in California. Most of these orchards are commercially viable for the most part.

The western region has some unique environmental qualities which contributes to the production of high quality nuts and the reduction in irregular production patterns. The most prominent environmental factor is the amount and quality of sunlight. The southwestern area of the United States has the highest solar radiation in the country. In addition, rainfall is sparse with 2-4 inches occurring during the growing season. This low rainfall occurrence coupled with low relative humidity and fast drying time reduces the incidence of disease (fungus) to little or none. The use of fungicides is virtually eliminated. Since the western region is outside the native pecan range, few damaging insects are prevalent except where introduced by man or migration with the forces of mother nature. Perhaps one of the major contributing factors to quality production is that of elevation. Many of the growing areas are located at elevations above 3500 feet. Basically this provides a temperature situation of cool nights resulting in reduced use of stored carbohydrates for respiration and greater use for photosynthesis, growth and nut fill. This temperature phenomena is also prevalent in the storage of carbohydrates after nut maturity in the Fall. Another temperature situation which occurs in the lower desert areas or extremely hot areas is that of pregermination or vivipary. This condition is a heat response in conjunction with poor nut fill, brought about by excessive respiration during the growing season. This excessive respiration is a major cause in the onset and perpetuates alternate bearing. In the lower elevation ranges and in the central valley of California harvest occurs prior to frost to avoid normally occurring November and December rains. Nuts are green harvested and artificially dried in order to prevent vivipary.

The soils of this Western region vary tremendously in terms of texture and formation. In general, soils are of alkaline pH. The physical variations included are the heavy alluvial soils of river valleys to sandy loams and loams in upland situations. It is not uncommon to find calichie in mountainous valley areas that are not alluvials. Calichie is calcium carbonate which is extremely high pH material which can lead to severe zinc deficiency problems. Soil sites become very important in relation to irrigation water quality and internal drainage. Water quality is a major factor in site selection as most well water contains sodium in large amounts which affects the tree and renders soil impervious to water. River reservoirs or river water also contain harmful salts but are chemically balanced with other cations or anions making them less hazardous to the soil and plants. In some situations soil amendments such as gypsum and sulfuric acid are utilized to counteract sodium.

As mentioned earlier, irrigation is a must to meet the water requirements (consumptive use ~52 inches/year) in these arid areas. Irrigation methods used by growers varies considerably depending on water supply. In areas where surface water is available orchards are watered with the basin irrigation method. In areas where wells are the source of water, trees are irrigated using various methods such as basin, furrow, drip, microsprinklers and solid set sprinklers. Each system has its advantages and disadvantages and a method is selected based on quantity of water, soil type, terrain, quality of water, cultural practices and user friendliness. The most efficient system in terms of cost effectiveness seems to be solid set sprinklers where wells are the major source of water. In areas such as irrigation districts where water is relatively inexpensive the basin method is used extensively.

The variety situation in the western region continues to be stable with the 'Western Schley' being predominant. During the establishment of orchards in the 1960's 'Barton'

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and 'Ideal' were planted as pollinators on a limited scale. The major pollinator variety planted for 'Western Schley' was the 'Wichita' because of its compatibility for pollination and potential early high yields of top quality nuts. The 'Western Schley' is well adapted to the Western region because of consistent yields, resistance to wind damage, cold hardiness, tolerance to zinc deficiencies and ability to self pollinate. Desirable nut quality characteristics include, high kernel percentage (58%), excellent color, thin shell and easy to shell. This variety is the mainstay of the industry and demands a good price.

The 'Wichita' in certain environmental situations is an excellent variety and is truly a moneymaker. The nut itself is medium in size lending to an inshell market. Nut quality characteristics include high percentage kernel (60%+) and good to excellent kernel color, even though discoloration can occur if nuts are exposed to high temperatures. Some of the disadvantages include: susceptibility to zinc deficiency, freeze damage in high elevation ranges and a tendency toward vivipary in low elevation hot growing conditions. As trees mature, it has a tendency to move into an alternate bearing cycle requiring some kind of pruning program to maintain nut quality and reduce alternate bearing.

The 'Ideal' variety has a good kernel color however the nuts tend to be small. The tree is consistent in production but yields are low compared to 'Western Schley' and 'Wichita'. This variety is susceptible to aphid population build up. Nuts seem to resist pregermination in the lower elevations. Varieties such as 'Cheyenne', 'Tejas', 'Shoshoni' and other USDA selections have been planted and to date have not been as consistent as 'Western Schley' and 'Wichita'.

Until recently, insects were not considered to be a major production problem because they were limited to the pecan aphid complex (black and yellow). In the late 1980's and early 1990's the pecan nutcasebearer (PNC) and hickory schuckworm (HSW) were detected in the Rio Grande River Valley near El Paso. Some areas of Far West Texas and Eastern New Mexico have observed both PNC and HSW for a number of years.

In general the yellow pecan aphid complex requires little use of insecticides. Biological control is an important grower program utilized in this region with the use of lacewing larvue and Harmonia ladybug. The black pecan aphid is controlled with low dosage applications of insecticides. These low dosages are used to preserve beneficial insects for yellow aphid control. For PNC and HSW continuous monitoring using phemone traps is in effect in the El Paso - Las Cruces area. Insecticide control of these two pests is limited.

The future of the Western U.S. pecan industry is bright. The average production potential (2000+ pounds/Acre) coupled with abundant sunlight, low rainfall, low incidence of diseases and insects makes commercial pecan orcharding a viable industry.

The major challenge for the industry in this Western region is to maintain high production and nut quality. In recent years as orchards begin to mature and crowd, some physiological problem have developed such as shuck decline. It appears that the thinning of trees within crowded orchards is a key to maintaining nut quality and consistent production. The development of new orchards via thinned transplanted trees is a common practice and seems to be the major method for expanding acreage compared to the use of nursery tree plantings. It is clear that this region will provide significant tonnage for consumption throughout the world.